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SOILS
FARM PRODUCTION AND MANAGEMENT

OTL

THEIR PROPERTIES AND MANAGEMENT

BY

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SOILS: THEIR PROPERTIES AND MANAGEMENT

CHAPTER I

SOME GENERAL CONSIDERATIONS

Thin broken and weathered fragments of rock that cover in a thin layer the outer part of the earth's crust that furnish the foodstuff and, in part, the sustenance for plant life, are termed soil. Soil comes from rock and returns to rock. It is merely a transitory stage in the change from one form of rock to another. It is never still. From the time when the particles leave the disintegrating rock until it is again cemented in the skeleton of the earth, it is subjected to almost constant movement and to the action of numerous forces that change it chemically and physically. It is the movement, the strain and the stress, the kind treatment at the hands of disintegrating agencies, that make the soil useful to plant life.

It was only the simpler forms of plants, however, that first drew on the pulverized rock. Time after time of plants has invaded the soil. Each has wrested from it the mineral matter necessary for its growth and development. Each has, in the end, left not only the mineral matter that it obtained from the disintegrated rock, but also the carbon and the oxygen that had been won from the

2. SOILS: PROPERTIES AND MANAGEMENT

air in the struggle for life. Primitive plants have been followed by more highly organized ones as the incursions have gone on, and always to the profit of the soil, until the soil has accumulated a great store of organic matter and a thriving population of microscopic life.

The effects of rock and plant matter that has accumulated through the centuries of struggle is the fertile soil from which man obtains his food. The study of this soil is a history of strife and struggle, and in the light of investigation is found as it, new conditions, new operations, new results, and new principles are brought to view and the story must be retold.

1. *Composition of the soil.*—Broadly speaking, the soil is composed of two general classes of materials, rock and organic matter. The former usually makes up the bulk of the soil, while the latter occurs under normal conditions in relatively small amounts. In spite of this low proportion, however, its presence is of vital importance in productivity. The soil has also three general phases—the physical, the chemical, and the biological. In the physical phase, the size and shape of particles, the movement of air and water, and other physical properties are dealt with; in the chemical phase, the composition of the particles of the organic matter, and of the soil solution and chemical impurities; in the biological phase, the soil is seen to be not an inert material, but teeming with life—minute forms of life, in its way, but of great importance in the manufacture of food for plants. Under these three general phases, then, the changes going on in a soil may be studied, and they are found to be directed primarily toward the production and maintenance of conditions favorable for plant growth. The soil is not a simple medium to study, but is extremely complicated

for two reasons: first, because of the complicated nature of its two general constituents; and secondly, because of the action and interaction of these constituents with each other.

3. *Factors for plant growth.*—The growth and development of a plant are largely the result of two sets of factors, the internal and the external. The former depends on the nature of the plant itself, the latter on its environment. The external factors of plant growth under normal conditions may be classified as follows: (1) mechanical support, (2) air, (3) heat, (4) light, (5) water, and (6) food. With the exception of light, the soil supplies, either wholly or in part, all the conditions named. As a mere mass of ground-up rock with which are mixed varying quantities of decayed organic matter, the soil acts as a medium for root development and thereby provides a foothold for the plant. Air, heat, and water are supplied as a consequence of the inherent physical condition of a soil. The circulation of water serves to bring food into solution for absorption by the roots. Then the two prime functions of the soil are realized—the supplying of plant-food and of a foothold for plant life.

3. *Plant-food elements.*¹—While the physical condition of the soil has tremendous influence on plant growth, the food elements must first be considered, since their availability is so closely related to the factors that function in soil formation. The elements are usually considered as absolutely necessary for plant growth. They may be classified as follows:—

¹ For a complete discussion of the plant-food elements as related to the plant, see Russell, S. J., *Soil Conditions and Plant Growth*, Chapter II, pp. 37-49. New York City: McGraw-Hill, 1916.

4. SOILS: PHOSPHORUS AND NITROGEN

| Elements obtained from air or water | Elements coming directly from the soil |
|--|---|
| Carbon | Nitrogen Magnesium |
| Oxygen | Phosphorus Iron |
| Hydrogen | Potassium Sulfur |
| Nitrogen | Calcium |

Carbon is obtained very largely by the plant directly from the air as carbon dioxide (CO_2); while oxygen comes directly from the atmosphere or from water, which is also the source of at least a part of the hydrogen utilized in vegetative growth. The other elements, except in the case of leguminous crops, are taken wholly from the soil solution itself.

While all these elements found in the soil must be available in order that plants may grow normally, only a very few ever become limiting factors. The three elements most likely to be lacking in a soil from a field standpoint are nitrogen, phosphorus, and potassium. They may be designated as the primary elements for plant growth. The other elements are usually present in amounts many times greater than will ever be needed by crops. Calcium, while necessary in large quantities in a soil, is largely an unabsorbed, and very seldom may limit plant growth because of being in too minute quantity to supply the food needs of a crop. The liming of a soil is for other purposes than the supplying of calcium for plant nutrition. Sulfur is supposed, in certain soils, to limit plant growth because of its insufficiency, but certainly it is never found in a minimum quantity.

Nitrogen exists in the soil largely as a product of the

¹ Boron, silicon, and strontium are found in plants, but are not essential to normal growth.

partially or wholly decayed organic matter present therein. It is utilized by the plant ultimately in the form of nitrate. The atmosphere, composed of four-fifths nitrogen by volume, has been the original source of this element; and through natural processes which are continually at work the nitrogen has been transferred to the soil. The unconsumption of this natural fixation, thus depending upon the great body of gas surrounding the earth, has become of great practical importance in agricultural operations.

Phosphorus has its origin in the mineral apatite and exists in rock soils largely as a tricalcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$). In case of a lack of lime or if the presence of considerable quantities of lime, phosphorus may be present as ferric or aluminum phosphates or as organic phosphoric acid. Phosphorus is probably taken up by the plant as the mono- or di-calcic phosphate (CaH_2PO_4 or CaHPO_4).

The potassium of the soil exists largely in holopne (K_2O , Al_2O_3 , 6SiO_2) or mica, or in hydrated aluminum silicates, which, while rather insoluble, supply potash to the soil solution in the bicarbonate, chloride, nitrate, or sulfate forms. It is from such compounds that the plant draws upon the soil for this element.

4. *Abundance of plant-food elements.*—Having considered the plant-food elements, especially those of primary importance, it is of interest to note their distribution in the earth's crust. Clarke¹ estimates the composition of the lithosphere, which makes up 92 per cent of the known terrestrial matter, as follows:—

¹ Clarke, F. W. *Data of Geochemistry*. U. S. Geol. Survey, Bul. 601, p. 22, 1916.

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| | | | |
|---------------------|-------|----------------------|------|
| Oxygen | 47.17 | Sodium | 2.52 |
| Silicon | 28.00 | Potassium | 2.49 |
| Aluminium | 7.84 | Hydrogen | .23 |
| Iron | 4.44 | Carbon | .19 |
| Calcium | 3.63 | Sulfur | .16 |
| Magnesium | 2.17 | Phosphorus | .11 |

The boldest summary of this table reveals the fact that the lighter elements are the more abundant in the earth's crust. The first four elements make up eighty-seven per cent, while the primary elements of plant growth either are lacking or are present only in very small quantities.

6. Soil-forming rocks. — As has been stated, ordinary soil is made up largely of inorganic matter which is derived from ground-up rock material. Therefore, the study of soil origin or formation, however cursory, the attention must be directed toward geological conditions, not because of their more geological interest but because of their ultimate bearing on soil fertility and crop growth. In the soil we expect to find, and do find, fragments of the commonest rocks, because from rock upward and down present in the largest extent of the earth's surface must be the means to break down into soil. Therefore the commonest soil-forming rocks are the rocks that are most so commonly in the field. They may be classified broadly under three heads—igneous, sedimentary, and metamorphic. Some of the common types are as follows:

| | | |
|------------|-------------|-------------|
| Igneous | Sedimentary | Metamorphic |
| Granite | Limestone | Schist |
| Syngite | Sandstone | Gneiss |
| Diorite | Shale | Micas |
| Diorite | Dolomite | Slate |
| Quartzite | | Quartzite |
| Peridotite | | |

The igneous rocks furnish material for the formation of the types constituting the other groups. They may be divided in a general way into two classes—one containing a high percentage of silica and some free quartz, the other having a medium or low silica content and no quartz. The former is designated as acid, and the latter as basic since it contains a high percentage of the silicates and the silicates with minerals. Granite and gabbro are excellent examples, respectively, of these general groups of rocks.

The sedimentary rocks, formed from material derived from the igneous rocks, have been deposited usually under fresh- or salt-water conditions. The development of pressure has in many cases been fundamental in the consolidation of this material. The firming and the chemical changes by precipitation may be expected to be comparatively outside rocks. Shale is merely a mass of low hydrated clay, while sandstone varies according to the cementing material which serves to hold its sand grains together. The cement may be iron (FeO_2), calcium carbonate (CaCO_3), or silica (SiO_2).

The action of heat, usually with pressure, on either igneous or sedimentary rocks, results in the third group, the metamorphic. Thus, granite on metamorphism may form either a gneiss or a schist; limestone or dolomite may form marble; shale may form slate; and sandstone may form quartzite.

On examination, ordinary rock is found to be composed of one or more minerals. In other words, it is a mineral aggregate. The mineral, in turn, is a natural compound of approximately a constant chemical composition, usually displaying a crystalline form and other well-defined physical properties. In order to illustrate the con-

1. SOILS: PROPERTIES AND MANUFACTURE

phases that may arise, the mineral composition of some common rocks is given below:

Granite—Quartz, orthoclase, and plagioclase with mica and hornblende.

Syenite—Orthoclase and mica with hornblende and apatite.

Diorite—Plagioclase and hornblende or augite with apatite, pyrite, and mica.

Peridotite—Olivine with augite, pyrite, mica, and hornblende.

Limestone—Calcium or magnesium carbonate with traces of silica and iron.

Sandstone—Silica cemented with iron, silica, or calcium carbonate.

This rough character of rocks has an important bearing on the question of soil formation, since the presence or absence of certain minerals may have considerable influence on the physical or chemical characteristics of the resulting soil. It is the minerals, therefore, rather than the rocks themselves, that must be looked to in a study of the great mass of inorganic matter, some active and some inactive, which makes up the bulk of ordinary soils. The question of the composition of a soil thus becomes more intimately connected with its origin.

8. Solifluid materials.—It goes without saying that many minerals have been discovered, melted, and changed, but only a comparatively few occur in any abundance in the natural soil. Nevertheless, it may be said that, practically all soils contain all the common rock-forming minerals. This is to be expected, as fragments of practically all the common rocks go to make up an ordinary soil. The

following list will give some idea of the minerals normally present in soils:—

COMMON SOIL-FORMING MINERALS

1. Quartz . . . SiO_2
2. Orthoclase . . . $\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$
3. Plagioclase . . . $\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$, $\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$
or combinations
4. Hornblende . . . $\text{Ca}(\text{MgFe})\text{Si}_2\text{O}_6$ with
 $\text{Na}_2\text{O} \cdot \text{SiO}_2$ and $(\text{AlFe})_2(\text{AlPO}_4)_2$
 SiO_2
5. Amphibole . . . $\text{Ca}(\text{MgFe})_2$ with $(\text{MgFe})_2$
 $(\text{AlFe})_2\text{SiO}_4$
6. Muscovite . . . $2\text{H}_2\text{O} \cdot 3\text{H} \cdot 3\text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$
7. Biotite . . . $(\text{MgFe})_2(\text{MgFe})_2(\text{AlFe})_2(\text{SiO}_4)_2$
8. Chlorite . . . $2(\text{MgFe})_2\text{SiO}_4$
9. Serpentine . . . $3\text{MgO} \cdot 2\text{SiO}_2 \cdot 3\text{H}_2\text{O}$
10. Pyroxene . . . $\text{H}_2\text{O} \cdot 3\text{CaO} \cdot 3(\text{AlFe})_2\text{SiO}_4 \cdot 4\text{SiO}_2$
11. Aegirine . . . $3(\text{CaFe})_2 \cdot 1(\text{CaSi})$ or (CaSi) or
 combinations
12. Zircon . . . $\text{ZrO}_2 \cdot \text{SiO}_2$
13. Olivine . . . $\text{H}_2\text{O}(\text{MgFe})_2(\text{MgFe})_2$
14. Calcite . . . CaCO_3
15. Dolomite . . . $\text{CaCO}_3 \cdot \text{MgCO}_3$
16. Gypsum . . . $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
17. Talc . . . $\text{H}_2\text{O} \cdot 3\text{MgO} \cdot 4\text{SiO}_2$
18. Hematite . . . Fe_2O_3
19. Magnetite . . . Fe_3O_4
20. Limonite . . . $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$
21. Kaolinite . . . $2\text{H}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$
22. Zeolites . . . Complex hydrated aluminous silicates of
 Ca, K, and Na as Fibrolite $(\text{CaMg})_2$
 $\text{Al}_2\text{Si}_2\text{O}_7 \cdot 5\text{H}_2\text{O}$

There are certain of these minerals that merit special attention because of particular attributes which they may impart to a soil. Quartz, for example, is very common in all soils, making up usually from 45 to 50 per cent of their composition. It is a make-weight material, however, as it is used to a very slight extent by most plants; but it adds a stability to the soil that perhaps the soil would not otherwise have, and this function is of considerable significance. Of greater importance from the plant-food standpoint are the feldspars, of which orthoclase is probably primary because it is the source not only of the soil potash. Indeed upon its physical and chemical agencies, it slowly supplies the soil solution with potassium, which in turn supplies the plant. The soils also very largely considerable potash for crop growth. The plagioclase, instead of being rich in potassium, as the feldspar (involves) contain the very basic elements, sodium and magnesium, so also do the pyroxenes and amphiboles represented by augite and hornblende. Olivine and serpentine, also silicates, are particularly rich in magnesium. Practically all the phosphorus in the soil, either organic or inorganic, has had its origin in the mineral apatite; yet this mineral is present in rocks and soil usually in very small quantities, making up not more than 0.6 per cent of the bulk of igneous rocks. Moreover it is a rather insoluble material. This fact, together with the small quantities occurring in soil-forming rocks, may account for the need of phosphorus in many otherwise fertile soils.

Calcium, so important as a basic material in soil, may be supplied to a certain extent by other minerals besides those already named—malakite, dolomite, and gypsum being perhaps the most important, especially the calcium

colours in either the crystalline or the amorphous forms. Huey of calcium in a soil tends not only to better physical conditions, but also to improve chemical reactions and biological activity. The loss of the soil minerals is of importance in the color relationship, for when combined to the hematite form a bright red may be imparted, while a yellow may result if limonite is produced. Color has great significance in a general estimate of soil productivity and is always an important factor in soil identification and survey. The tendency of most iron compounds in the soil is toward the hematite or the limonite form when subjected to oxidation and hydration.

Kaolinite is a product of rock decomposition and is considered to be of considerable importance in most clays or clay horizons. It is almost always impure and in this form is designated as kaolin. Kaolin and the soil sesquioxides, which are hydrated aluminium silicates carrying chiefly sodium, calcium, and potassium, are really fine and products of rock along soil direction are secondary minerals. Consequently they must always be considered in any study of soil formation or of soil utilization, particularly as they may serve to enrich the soil solution in phosphate held by them in physical and chemical combinations.

† Relative abundance of minerals — Wollastoff¹ presents the following table as a result of his examination on the distribution of certain minerals in the earth's crust:—

| | Percentage | Percentage |
|--------------------|------------|------------------------------|
| Pyroxene | 48 | Orthoclase 1 |
| Quartz | 55 | Ilmenite, rutile, etc. . . 1 |
| Mica | 8 | All other minerals . . . 8 |
| Feldspar | 5 | |

¹ Bull. A. D. C. No. 866, p. 15. New York City: 1907.

This agrees in general with the distribution of these minerals in the earth's surface and accounts for their universal presence in all soils.

8. *Organic matter.*—The minerals as listed account for all the minerals of plant-food obtained from the soil except nitrogen, which, as already indicated, is found very largely locked up in partial and other nitrogenous material. The incorporation of organic matter in any soil, either by natural or by artificial means, besides tending to better its physical condition also enriches it in its total, or gross, nitrogen content. Though this organic matter is so necessary to a fertile soil, its addition and thorough incorporation occurs late in the process of soil formation. Through the agency of bacteria and other organisms the organic compounds are slowly simplified, new compounds are split off, and nitrogen is introduced into the soil solution, mainly as nitrate, which is one of the principal forms in which it may be used by plants growing on the soil.

9. *The soil and the plant.*—Unworked from the agricultural standpoint, then, the soil becomes purely a medium for crop production. Its composition, both mineral and organic, is of vital importance in the furtherance of such a use. All the physical, chemical, and biological agencies become directed toward this end. The study of the soil and a better understanding of its functions will allow the great class of husbandmen not only to increase their crops, and consequently their profits, but at the same time to maintain as far as possible the fertility of our greatest national resource. A rational study of the soil should ultimately lead to a study of conservation in its broadest both to prevent prosperity and to the yellow of poverty.

CHAPTER II

SOIL FORMING PROCESSES

ATTACK the first proper estimate of the relations between the rock and the soil, the next step is toward the mode of soil formation and the agencies concerned. As might be expected, this is a complicated problem from the fact that most rocks are so heterogeneous in their composition. The question becomes still further involved because of the many factors that are continuously functioning in rock decay. This process of the breaking down of rock masses and their gradual evolution into soil is called *weathering*.¹ Rock weathering may be defined specifically as the changes that rock masses undergo due to the physical and chemical activities of atmospheric agents. Everything on the earth's surface is seeking a more stable condition, and therefore, from a geological standpoint, is continually changing. If a rock represents a more stable condition than the exposed rock, the rock slowly evolves toward the soil. Again, if a soil presents conditions not wholly stable, that soil will change by an elimination or an addition of these components. The soil, then, is a geologic unit. It is a transition product from one condition to another.

This weathering, which brings about such changes and is such a factor in the modifications of our topography, is

¹ For a complete discussion of weathering, see *Howell, G. F. Rocks, Soil, Weathering, and Soils*. New York, 1939.

very superficial and affects the earth to but relatively shallow depths. However, from the fact that it provides a medium for crop growth and at the same time is largely instrumental in maintaining the fertility of this medium, its agencies and processes become of great significance.

The forms of weathering, while very diverse not only as to nature but also as to product, result of an action so close that the true relationships at once become apparent. This classification may be made under two heads, *mechanical* and *chemical*, as follows:—

Forces of weathering

I. Mechanical changes, or disintegration

A. Erosion and denudation

Water, wind, ice

B. Temperature

Heat and cold, wet and frost

C. Plants and animals

II. Chemical changes, or decomposition

A. Oxidation and carbonation

B. Ureidation

C. Hydration

D. Solution

12. Water.—The three great agencies of erosion and denudation are water, wind, and ice. They are instrumental not only in the breaking up of rocks, but also in transporting the resultant materials. Water is especially of importance, water denuding effects are very rapid when viewed over geological periods. It is estimated that the United States is being *planned* down at the rate of one inch in seven hundred and sixty years. This is rapid enough to fill the Panama Canal in seventy-three days.

The water, in order to be a successful eroding agent, must be laden with sediment, so that its carrying power largely determines its power of erosion. In other words, it must be stirred.

From the time when the winds begin to blow on a surface until they have been gathered into storms and storms are finally discharged into the ocean, they are engaged in moving the detrital matter already produced. The Mississippi River is working fast enough at the present time to reduce the mountains of North America to sea level in four million years. The Appalachian Mountains, born in Paleozoic times, have lost easily worn material more rapidly for us to view. Our river and lake soils are due to the cutting and carrying power of the streams. The deltas, and the marine soils of the Atlantic and Gulf coasts, afford other examples of such effects. The continual pounding and grinding of waves are no mean factor in rock disintegration. The sanding of the sands is a mute evidence of this great force.

II. Wind.—The wind as a softening agent has, like water, two phases of action—erosive and transportive. Sweeping over the land as dry weather, it has the power of picking up innumerable fine particles which may settle out very uniformly over a tract of years. The lifting of exposed rocks, especially in arid regions, the undermining of cliffs, and the picking of stones to a tremendous equal to that of glass, are frequent occurrences. The weighing of windstones is known over the sandbars during severe storms, and the flight of all loose stones, and of persons seated. Great areas of soil have been deposited by winds, especially in the United States. The loess of the Mississippi Valley and

the whole of the Southwest over their origin, at least partially, to the carrying power of wind at a time when activity existed over all this area.

II. Ice. — When in large bodies, as in glaciers, ice exerts a tremendous grinding power. Moved on, by its mobility and viscosity, always liable to all topography, and as it moves slowly forward it grinds and wears and abrades even the hardest rocks. The great masses of pebbles and rocks which are picked up and imbedded by glaciers, especially in their lower surfaces, increase their cutting power many fold. The effect of glaciers is of particular interest because of the fact that all of the northern part of the United States was once at one time with a great ice sheet, and our northern soils are the either directly or indirectly the advanced and retreats of this ice sheet. Formed in northern latitudes due to a change in climatic conditions, the ice sheet slowly covered many thousands of square miles of territory, and as the ice was usually several thousand feet thick, hills, and other mountains, were overthrown. Their tremendous weight made the grinding action almost irresistible. In the retreat, or melting back, of the ice, a mass of the ground up and well-sorted material was deposited as soil; while the streams flowing from the front, or into glacial lakes, were furnished with heavy sediments for distribution in other regions.

III. Heat and cold. — The changes in temperatures of the air, and the soils and rocks, tend mostly to augment the effect of the denuding agents. Constant expansion and contraction is productive of weakness and different physical breakdown. Heat is conducted slowly through rocks, this leading to differential heating and unequal expansion or contraction. Rocks, as already noted, are

minally mineral aggregation, and these minerals vary in their coefficients of expansion. With every change of temperature, differential stresses are set up which ultimately must produce a considerable effect. When the separate minerals expand they expand differently, and when they contract they contract again, assume quite their former relationships to one another. Thus cracks, cracks, and rifts are created in rocks, especially those of heterogeneous mineral composition. The expansion coefficient of granite is .000044 of an inch to a foot for every degree Fahrenheit, while that of marble is about .000056 of an inch. This seems to be very slight, but it must be remembered that under natural conditions large masses of rock are concerned. A sheet of granite 100 feet long will expand one-half an inch with a change of 75° Fahrenheit, which is not an uncommon variation of temperature in arid regions or high altitudes. This leads to slipping, tilting, and exfoliation. The rock fragments may range from microscopic sizes to large blocks, which are often split off with great violence.

14. Frost.—Frost as is the action of a slight change of temperature, its effects become many fold more apparent when water is present. We then have the action of frost. The cracks and crevices made by heat and cold fill in a humid region become filled with water. This moisture, on freezing, exerts a very great force. The expansive power of water passing from the liquid to the solid state is equal to about 150 tons to a square foot, which is equivalent to the weight of a column of rock about a third of a mile in height. Moreover, most rocks contain a certain amount of water in themselves. This water is recombined in successive operations as quarry water. The passage of the quarry water to a solid state

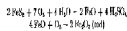
must result most directly to the physical condition of the rock. This action of frost is by no means complete when the rock is fixed mechanically to a wall, but is contained on the soil itself. Such further fixing is of the greatest importance in bettering the physical condition of the soil, and is usually designated as a *weathering and chipping and flaking and churning process*. It is to such forces, more than to any other action, that the farmer owes the good *tilth* of his soil.

36. Plants and animals.—Plants and animals unite their forces with those already mentioned to bring about further physical change. While the modifications due to erosion, denudation, and temperature, these agencies affect them to a greater extent than they affect the parent rock. In other words, they begin their work after the minerals have been reduced, at least partially, to the form of a soil. Single plants, as mosses and ferns, will develop readily on rock ledges and cause rock fragments. They send their roots into the crevices and exert a prying and loosening effect. They also catch dust, provide humus, and gradually accumulate a soil in which higher and still higher species of plants may grow. Their chemical effects, especially regarding solution and oxidation, aid in this disintegration. The distribution of organic matter through the soil by the excretion and death of plant roots is of no mean importance in soil fertility. Insects also may be a factor in rock decay, not only through their action on the humus material but also through a direct attack on the rocks themselves. Their influence, however, is probably mostly chemical.

Animals also effect the *tiling* of rock fragments and soils, from their burrowing and mixing tendencies. Such rodents as gophers and squirrels open up the soil, thus

providing better circulation of air and water. This brings about a deeper and more effective action of the other physical agencies of weathering. Furchons produce similar effects. Their holes provide channels for ready drainage, and large quantities of soil are brought to the surface freely by them. Darwin estimates that this accounts for as much as one or two inches in a decade.

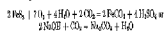
16. *Oxidation and carbonation.* The physical and chemical forces do not act alone, but, as a general thing, combine in their efforts. They are not of factors *à la* and accelerates the other. Slowly but the disintegration of a rock begins, then, before its decomposition is also apparent. Of the chemical forces oxidation is usually, especially near the surface of the earth, the first to be noticed. It is promptly manifested in rocks carrying iron, and consists in such a change that the added oxygen may be accumulated. Silicates readily absorb and become oxides, while these same oxides are prone to take up oxygen to their fullest extent. This oxidation is followed by a loosening of the rock, which is first stratified and stained with iron oxide but at last changed to a uniform color. The change may be exemplified by the following reaction:—



While not all the minerals contain iron, enough of them do to impart a tinge of weakness to most rocks. The ferrous oxide (FeO), being soluble, is washed out and the rock is weakened and crumbled. A way is now open for more energetic physical and chemical decay.

With the weathering action there is also the influence of

carbon dioxide (CO_2), which is universally a constituent of air and is a product of the decaying vegetable matter present in most soils. This means that the water circulating among rock fragments, especially those of a soil, is heavily charged with this compound. The carbonation may be illustrated as follows:—



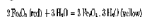
12. **Decalcification.**—Decalcification is the opposite reaction to calcification, being a form of oxygen rather to the air or to some other compound. With benzite it might take place as follows:—



Under normal conditions, however, it is not a very important factor, since most rock fragments and soil are fairly well saturated, at least too well saturated to allow this reverse process to occur. In poorly drained soil or in soil very rich in humus and decaying organic acids it may occur, and is usually manifested by the development of blue and gray colors, indicating that a reduction has taken place. The bleaching of sands, sandstones, and clays may be due partially to this, and also to a removal of the ferrous salts in solution. Some sands display this phenomenon. The average farmer, however, need not concern himself with the injuries that may result from decalcification.

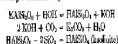
13. **Hydration.**—Hydration usually accompanies calcification, but when occurring at great depths it may be practically the only change the minerals have undergone. Minerals, especially feldspars, become clouded and lose their luster on the assumption of chemically combined

water. There is also a considerable increase in bulk, this being often as much as 80 per cent during the conversion of a rock to a soil. Igneous minerals, while apparently solid, quickly crumble when exposed to fumes of acidifying which are more superficial in their effects. Carbonation and oxidation usually take place as consecutive actions with hydration. A simple example of hydrolysis is shown in the change of feldspar to kaolinite, which occurs in practically every case when there is allowed to weather from granite or a similar suite to the higher forms:—



15. Solution.—As it is now quite evident that weathering, especially the chemical weathering, is largely a simplification of compounds, and that water is almost universally present, some solution must occur. These simple materials are particularly prone to enter solution because of the presence of carbon dioxide, which, by acidifying the soil water, intensifies its solvent action to a considerable extent and consequently increases its power as a weathering agent. The atmosphere contains amounts of this gas ranging from 1.57 to 4.48 parts in 10,000, while considerable amounts are brought down on the rocks and the soil in rain and mist. The carbon dioxide evolved directly into the soil water from decaying organic matter also aids in keeping the soil charged with this gas. This means, then, that solution is largely a process of softening, especially after the soluble constituents have been drawn out into the soil solution. It is evident that oxidation, carbonation, hydration, and solution act in unison in being about the chemical decay of the rock and the soil. This combined action may be represented

by showing the various stages that orthoclase may undergo in producing a residual clay:—



The silice in this case may become quartz or colloidal silica, or, what is more probable, may unite with certain elements to produce various hydrated silicates.

III. A general statement of weathering.—The question of rock weathering is complicated because no one action can be considered alone. All forces are acting together, leading to produce a great complex of reaction and interaction. No amount of explanation or speculation can ever fully clarify the question as to the formation of a soil from a parent rock. Nevertheless, looking in general the separate forces and reactions produced, we may formulate the phenomenon in a general and superficial way. The change that a rock undergoes in the formation of a residual clay is first a physical breaking down accompanied by chemical changes, which consist in the hydration of the feldspars, the oxidation of the iron, and the solution and recombination of the soluble bases.

II. Factors affecting weathering.—It is readily to be seen that the activity of the various agencies of weathering will be modified by certain factors which determine not only the kind of rock decay but also its rate. Of these, climate is probably of the greatest importance. The difference in the weathering in an arid region as compared to that in a humid region will illustrate this point. Higher soils conditions the physical forces will dominate and the weathering will be coarse. Freezing and thawing, heat and cold, the action of the wind, and

the effect of animals will be about the rate agents. In humid regions, however, the forces are more varied and practically the full quota will be at work. Chemical decay will accompany the disintegration, and the resultant products will be finer and more minutely divided. The aqueous minerals will show also the change of color and loss of luster due to the decomposition of some of their essential elements. The same rock, then, will behave differently under different climatic conditions. A granite, for instance, is a very durable rock as compared with a limestone, and in a humid region where chemical agencies are dominant it would be markedly more resistant. If, however, these two rocks are placed under conditions where the physical forces are potent, particularly in regard to change of temperature, the comparison is different. The limestone, being homogeneous, is not affected by atmospheric changes; but the stones cut up in granite due to differential contraction and expansion must ultimately reduce it to fragments.

As weathering is confined to the very surface of the earth, the exposure or position of a rock will determine the kind and the rate of decay. If the rock is very deep below the surface, only hydration may occur; while if it exists as an exposed ledge the full force of the weathering agents will be sustained. If the effect of the changed rocks is not removed, this serves as a blanket for the protection of the rock below. The transmissive power of weathering is important in maintaining a river section for action.

The texture of the rock is also a factor. Other things being equal, a closely crystalline rock will disintegrate and decompose more rapidly than one of fine grain. The coarser the grain, the larger the amount of interstitial

quies and the greater the convergence to physical agencies. As physical changes open the way for chemical change, various textures will ultimately encourage decomposition as well as disintegration.

Clearly, the disintegrative force of the rock will be influenced by the chemical composition of the minerals and the mineral composition of the rock. A rock made up of minerals that offer but little resistance to decay will naturally rot away readily and quickly to a soil. Rocks that very largely have minerals which are so fractious in their nature, however, may never decompose for enough or rapidly enough to give a soil of any agricultural significance. The next step, then, in the study of soil formation is a consideration of the relative resistance of the minerals and the rocks.

32. *The law of minerals and rock decay.*—Considerable work has been done on the comparative solubility of minerals both in pure and carbonated water, but in most cases it has proved somewhat unsatisfactory. Nevertheless we are able, by consulting the work of Miller,¹ Clark,² Dana,³ and others, to arrange some of the commoner minerals in the order of their solubility, the most resistant minerals heading the list:—

- | | | |
|---------------|------------------|--------------|
| 1. Quartz | 6. Epidote | 11. Analcite |
| 2. Microcline | 7. Serpentine | 12. Olivine |
| 3. Biotite | 8. Talc | 13. Calcite |
| 4. Orthoclase | 9. Diacetyluride | |
| 5. Phlogopite | 10. Augite | |

¹ Miller, R. *Solubility of Rocks in Carbonated Water*, *Lab. 244 Geol. Smithsonian*, Vol. XXVII, p. 25, 1877.

² Clark, F. W. *Data of Geochemistry*. U. S. Geol. Survey, Vol. 53A, p. 405, 1907.

³ Dana, J. *Solubility of Minerals*. *Revue de Géol. Supplément*, pp. 22 and 322. Paris, 1867.

The next step is to select some general law which can be shown to govern the resistance of these minerals. Such a statement would aid considerably in the making of general deductions regarding weathering. The relative content of some of these minerals, taken in the order as above, shows considerable light on this phase:

| The west of Silesia | | The east of Silesia | |
|---------------------|-----|---------------------|------|
| Quartz | 100 | Hardite | 45 |
| Orthoclase | 45 | Clivine | 41 |
| Plagioclase | 45 | Calcite | 3000 |

Another case might be cited in a comparison of the chemical composition of anorthite, hardite, and clivine:—

| | |
|-----------|---|
| Anorthite | $\text{CaAl}_2\text{Si}_2\text{O}_8$ |
| Hardite | $\text{Ca}(\text{Mg}/4\text{Al}_3\text{SiO}_8)$ with $\left\{ \begin{array}{l} \text{NaAl}_2(\text{SO}_4)_2 \text{ and} \\ (\text{Mg}/2)(\text{Al}/2)(\text{SO}_4)_2 \end{array} \right.$ |
| Clivine | $(\text{Mg}/2)(\text{SO}_4)$ |

It is to be noted that immediately as the resistance of a mineral declines, its content of silica decreases and the percentage of the basic constituents increases. Silica and aluminium, then, make resistance to decay; while sodium, magnesium, sodium, potassium, and iron facilitate its increasing susceptibility to decay. The law of mineral resistance may be formulated as: "The more basic a rock becomes, the more rapid is its decomposition; and the more acid, the less rapid is its decay."

This general law certainly should apply to rocks that are made up of the minerals listed above. One example will show this clearly. The apophyllite, as already stated, may be divided into two groups, acid and basic:

BRIDGEMAN, H. G. "The Formation of Hardite (Fayalite) from Anorthite." *Proc. Roy. Soc. Lond.*, p. 361, 1907.

This acidity and basicity is determined by the presence of silica and the alkalis, respectively, as carried by certain essential minerals. Therefore, we name some representative igneous rocks in the order of their acidity, and list some of the minerals carried by them:—

1. Granite . . . Quartz, orthoclase, and silica
2. Diabase . . . Plagioclase, mica, hornblende, or amphibole
3. Trachyte . . . Primarily alkalis

It is to be seen that the minerals contained by granite are more resistant than those carried by either the diabase or porphyrite, while the alkalis of the last group is near the foot of the list when the minerals are arranged in the order of their resistance.

The following data¹ have not the accuracy presented above as to the relative resistance of rocks:—

PERCENTAGES LOST IN FIVE HOURS' EXPOSURE TO FALLEN HYDROGEN SULFIDE FROM FINE GRANITE, GRANITE, AND DIABASE

| | Granite | Diabase | Albite |
|---|---------|---------|--------|
| H ₂ S | 31.66 | 12.65 | 0.19 |
| Al ₂ (SO ₄) ₃ | 17.91 | 15.51 | 8.24 |
| CaO | 1.52 | 1.29 | .40 |
| MgO | .40 | 1.20 | .75 |
| SiO ₂ | .26 | 1.21 | 1.68 |
| Na ₂ O | 5.65 | .50 | 1.23 |
| | 41.46 | 35.53 | 22.62 |

It is evident, then, that the use of mineral resistance applies to rocks as well as to the separate minerals, although its application becomes in such cases complex and difficult to interpret.

¹ Merrill, G. T. *Diabase, Rock Weathering, and Soils*, p. 164, New York, 1914.

28. *Special cases of weathering.*—The weathering of granite and limestone under different climatic conditions has already been compared. The changes that take place in these rocks as they are exposed to various clays may now be considered. The following examples serve to show in what elements the losses are likely to be most serious during the process:—

Table. *Granites and the Associated Clays?*

| | Rock | Clay | Percentage Loss |
|--|-------|-------|-----------------|
| SiO ₂ | 55.00 | 45.31 | 19.45 |
| Al ₂ O ₃ | 15.00 | 20.15 | 30.00 |
| Fe ₂ O ₃ | 3.00 | 12.15 | 14.25 |
| CaO | 0.15 | 0.10 | 30.00 |
| MgO | 1.00 | .40 | 55.75 |
| Na ₂ O | 0.25 | 1.10 | 77.25 |
| K ₂ O | 2.80 | .20 | 92.85 |
| Ignition | 35 | .37 | 99.00 |
| | 85 | 52.75 | Clay |

Table. *Limestones and the Associated Clays?*

| | Rock | Clay | Percentage Loss |
|--|-------|-------|-----------------|
| SiO ₂ | 7.42 | 55.37 | 87.20 |
| Al ₂ O ₃ | 1.55 | 22.44 | 93.00 |
| Fe ₂ O ₃ | .30 | 7.33 | 95.50 |
| CaO | 50.20 | .51 | 99.00 |
| MgO | 10.17 | 1.21 | 88.00 |
| Na ₂ O | 1.10 | 0.51 | 54.50 |
| K ₂ O | .10 | .35 | 70.00 |
| Fe ₂ O ₃ | .10 | .10 | 88.75 |
| CO ₂ | 41.57 | .30 | 99.45 |
| Ignition | .57 | 6.80 | 91.60 |

¹ Merrill, C. P., *Ind. Eng. Res. Assoc.*, Vol. 6, p. 103, 1917.
 Edgar, J. A., *U. S. Geol. Survey, Bul. 130*, p. 265, 1892.

Sills have resulted in both cases from the decay of these rocks. In the case of the granite the resulting soil was a deep red clay, with quartz grains present. The soil from the limestone was a plastic clay, high in silica and aluminum. Leaching has probably gone on to a very great extent in both soils. It is probable also that the basic constituents have entered the porous loam, especially calcium, magnesium, sodium, and potassium. The evidence has almost wholly disappeared from the limestone clay, showing that a limestone soil may not necessarily be rich in lime. As a matter of fact, the farmers say that if it is mixed it will be lacking in that respect. When shown diagrammatically (Figs. 1 and 2), the changes that the parent rocks have undergone chemically in forming a clay will become apparent.

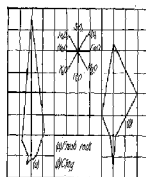


FIG. 1. — Diagrammatically representing of the chemical transformation of parent rocks into red and black clays. (See text for details.)

WILL-MING-KAO PROGNOSIS

As shown by the diagram, the soil from the granite does not differ greatly from the original rock, except in loss of bones, absorption of water, and increase of organic

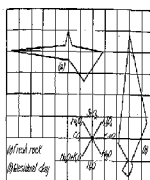


FIG. 2.—Diagram showing the chemical composition of Virginia Blue clay and the residual clay. The numbers above the lines indicate the percentage of each element.

matter. The residual clay from the limestone presents greater differences due to the almost entire disappearance of calcium carbonate. The diagrams for the two clays resemble each other fairly closely in spite of their widely differing sources. This may be due to the persistence and accumulation of siliceous, aluminous, and iron, and a loss of the basic materials, all soils as they weather tend to approach a similar composition. Yet, owing to a difference in the adjustment of the forces at work and in the time element, no two soils will ever be exactly alike. Soils will differ, then, from the original rock and from one another according to the intensity

SOIL: PROPERTIES AND MANAGEMENT

and character of the weathering and the constitution of the parent materials.

4. Practical relationships of weathering.—Weathering processes result in a general simplification of compounds. Their action first affects the rock, with the result that a soil is produced; but they still remain active in the soil after it is in a condition to support plants. The physical process especially tried is loosening of the soil, contributing largely to its tilth. The farmer encourages such influences by plowing his land and by other operations. When a soil, after such weathering action, the soil would become physically unable to afford food for plants. The continual chemical changes resulting in solution and carbonation provides a soil water rich in plant-food material. Weathering, then, by a slow process over geologic periods has provided us with soil, and by the same slow process is maintaining the fertility of this creation. The consequent soil control of such an agency is of unusual importance in agricultural practice.

CHAPTER III

THE EMPIRICAL CLASSIFICATION OF SOILS

Soilsciences must be considered as a fielding soil test in soils and in rocks. This gives two general classes of volcanic—those that have not been shielded far from their place of origin, and those in the formation of which the transporting agencies have been instrumental. These two general groups, designated as secondary and transported, are subject to considerable subdivision, as follows:—

| | | |
|-------------|----------|----------------------|
| Secondary | Residual | Clastic |
| | | |
| Transported | | Gravity -- Colloidal |
| | | Water -- Alluvial |
| | | Wind -- Lenticular |
| | | Ice -- Glacial |
| | | Wind -- Eolian |

35. **Residual soils:** This group of soils covers wide areas of our available regions and comes from many kinds of rocks. Residual soils are all soils, the extent of which we have to deal in agricultural operations. Since a

¹See Proceedings, A. C. A. Classification of Chemical Soil-
wells, Jour. of Geol., Vol. 22, No. 4, pp. 420-426, 1914.

residual soil is formed *in situ*, the rocks that underlie it, if known, show the *chemistry and composition* of the rocks from which the soil was actually a product. In such soils the changes that a rock undergoes in becoming a residual clay are to be studied to the best advantage. An examination of the various grades of material that are local overlying the country rock (Fig. 3) is no new when

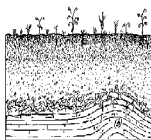


FIG. 4. The gradual transition of country rock into residual soil by weathering *in situ*.

this residual material, which some or less accurately the *gradation* from rock to soil. Residual soils, besides being old soils, are usually *unconsolidated* and present a *heterogeneous mass* of material. Since they have been subjected to *loading over vast periods*, a very large amount of the *mobile materials* have been *washed out*, leaving to have high percentages of the *permanent materials*, such as *silica, iron, and aluminum*. An analysis of an *Achuan formation*, its residual clay and the calculated percentages of the *various constituents* present in the *fresh rock*, illustrate this point:—

ANALYSES (continued) AND THE RESIDUAL CLAY¹

| | Iron Oxide | Clay | Percentage Loss |
|--|------------|-------|-----------------|
| SiO ₂ | 4.35 | 52.39 | .76 |
| Al ₂ O ₃ | 4.19 | 52.30 | 11.25 |
| Fe ₂ O ₃ | 5.54 | 1.19 | 25.56 |
| MnO ₂ | 4.57 | 11.00 | 37.59 |
| CaO | 44.79 | 7.59 | 98.49 |
| MgO | .20 | .56 | 46.39 |
| K ₂ O | .35 | .46 | 99.59 |
| Na ₂ O | .16 | .31 | 93.59 |
| Cl ₂ | 24.10 | .00 | 100.00 |

The vast age of such soils tends to bring about great oxidation, so that most of the iron has changed to hematite and limonite. Since almost all soils contain considerable iron, the prevailing colors of residual soils are red and yellow, depending on the degree of oxidation and hydration. Grays and browns may exist, however, where iron has been leached or oxidation has been feeble. In texture such soils usually present very fine conditions. Having been attacked by both the physical and the chemical agencies, the particles have been reduced to a very fine state of division. Over residual soils the heavier soils predominate, as silty, silty loams, clays, and clay loams. Very often sand or chert may be present, having been a constituent of the original rock mass.

An examination of the particles of a residual soil usually shows them to be in an advanced stage of decay. The feldspars have lost their luster and have become opaque. The iron has become oxidized, and the stable bases have

¹ Thomas, J. C. P. *Ann. Rept. Geol. Survey Arkansas*, Vol. 1, p. 675, 1901.

other disappear or change their contribution to most stable forms. The tendency of all soils is toward a condition of equilibrium, and consequently they approach, but never reach, a uniform composition. This does not apply to their productivity, because many other factors besides chemical composition go to determine cropping power. Reddish-brown soils, therefore, bearing poorer soil power in time as their age increases. The organic matter of residual soils largely depends, in amount and condition, on climatic factors. If rainfall and temperature, for instance, are favorable for the rapid and continual development of a natural vegetation, the soil will be rich in humus, so rich at times as to make to a certain extent the red color so characteristic of such soils. If plants do not grow well on this soil, however, it will be low in organic matter and probably in poor physical condition, so vital is humus to a proper foothold for plant life. Two residual soils coming from the same kind of rocks may vary rather widely in their general characteristics, especially as to crop productivity.

26. *Distribution of residual soils.*—Residual soils are of wide distribution in the United States, particularly in the eastern and central parts. A glance at the soil map of this country (see Fig. 4) shows that great provinces—the Piedmont Plateau, the Appalachian Mountains and Plateau, the Limestone Valleys and Uplands, and the Great Plains Region. The age of these soils varies in the order named, showing that while they are very old on some points, other soils yet to be discussed, there may be vast periods of geologic time between their beginnings. As a matter

¹⁷The soil distribution of the region and its characteristics of the soil of the United States, see Hartney, 177, and volume 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100.

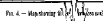


FIG. 4.—Hypostomus affinis.

of fact, there is probably a greater difference in age between the soils of the Piedmont Plateau and those of the Great Plains region than has appeared since the latter were formed. The soils of the Piedmont Plateau have been formed mostly from granite soil rocks. In fact, the Piedmont Plateau is the remnant of the old continent, Appalachia, which was in existence in early Cambrian times. The rocks of the Appalachian Mountains and Plateau are limestone, sandstone, and shale. The Great Plains region presents limestone, sandstone, and shale of the Cretaceous, Tertiary, and Quaternary ages, besides much unconsolidated material. The soils of these provinces, extending as they do over great areas, vary within wide limits due to rock formation, climatic conditions, and age; yet certain numerous characteristics, so clearly pointed out, are exhibited by all.

22. *Continental soils*.—This type of soil is of a very different character from the one just under discussion, being made up largely of organic matter with the mineral constituents of secondary importance. Its relatively recent periods shallow lakes, ponds, and bays were formed, partly by stream action, partly by marsh conditions along sea or lake coasts, or, what is commoner in the northern part of the United States, by glaciation. Any basin that contains water throughout the year serves as a place for the formation of continental soil. The highly favorable moisture relations along the banks and shores of such standing water encourage the growth of many plants such as alge, moss, reeds, flags, pines, and the like. These plants thrive, die, and fall down only to be covered by the water in which they were growing. The water shifts and the air is a large reflect, retards rapid oxidation, and thus acts as a preservative for the rapidly collected

big organic matter. Year after year the process goes on, and year after year the bed of nitrogenous material becomes deeper and deeper. Large shrubs, and even forests, often grow on such beds. Time and the bed of water are the factors that may limit the depth of such beds. Accumulations of this nature are found behind river the water marshes. Their size may vary from a few acres to several thousand. Along streams the old abandoned beds offer a common opportunity for the beginning of such accumulations. Along large bodies of water, swamps, either salt or fresh, may allow the process to go on. Shallow basins scraped and gouged out by advancing glaciers are frequently occupied by such material. In the last-mentioned case the beds are more or less independent of topography, and may be found on hillsides, or even on hilltops, as well as in the lower basins.

Glaciated materials may be grouped under two broadest and widest. The only difference is in their degree of decay. In part the decay and redistribution of the original plants can still be detected, and identification is quite possible. In much, however, the preservation and decay have gone so far that the plant decay has lost its identity as such and is merged into that complicated and indistinct material called humus. The composition of peat and musk may be much altered by the weathering of mineral matter from above. In some cases the beds may be from 80 to 95 per cent organic, while in other cases due to the foreign material, the percentage may drop to as low as 15, giving a block or massy earthy soil.

The following analyses illustrate the composition of representative composite soils:—

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| | 1 | 2 | 3 |
|---------------------------|-------|-------|-------|
| Adjusted matter | 31.45 | 24.75 | 35.69 |
| Organic matter | 56.45 | 57.75 | 15.77 |
| Slime | 1.52 | 2.75 | — |
| Silt | 5.51 | .81 | 3.4 |
| Sand | .87 | .45 | .86 |
| Marl | — | 2.69 | 3.22 |

1. Wash. —Hobbs, O. M. *Marls. Composition and Disposition*. Mo. Rep. Res. Bul. 13, 1897.
 2. Wash. —Hobbs, O. M. *Soils of the Potomac*. Mo. Rep. of Res. Bul. 13, 1897.
 3. Wash. —Hobbs, O. M. *Soils of the Potomac*. Mo. Rep. of Res. Bul. 13, 1897.

Black soils, while usually not of large extent, because of excessive water when drained, especially if they are used as a good market. They are of particular value in making open soil, being adapted to such crops as cotton, corn, soybean, and the like. Usually they must not only be provided with drainage, but also be treated with fertilizers carrying phosphorus and, especially, potash. It is also a good practice to start vigorous decay by the application of barnyard manure, as the nitrogen carried by such soil is usually not very readily available to plants. In many cases sand and peat may be extracted at varying depths by water, which is a soft, porous medium. Before and at the beginning of the complete accumulation these basins were inhabited by millions, which on death deposited their shells on the bed of the lake. These shells are now found in a more or less fragmentary condition, usually mixed with sand and clay and covered to a varying depth with peat or mud. Such material, because of its richness in lime, is valuable

as a soil amendment, and often when it is found good enough in quality and in sufficiently large quantities it is handled commercially. When it contains large amounts of phosphorus, as it does in some cases, it may be used as a fertilizer. The following analyses¹ show the general character of this soil:—

| | 1 | 2 |
|--|-------|-------|
| SiO ₂ | 25.28 | 1.65 |
| Al ₂ O ₃ .Fe ₂ O ₃ | 3.02 | 1.21 |
| CaO | 37.03 | 6.45 |
| MgO | 43 | 5.96 |
| As ₂ O ₃ | 28 | .55 |
| P ₂ O ₅ | 25 | .30 |
| K ₂ O | 40 | Trace |
| Na ₂ O | 20.02 | 33.60 |
| Insoluble | 1.17 | .55 |

28. *Colluvial soils*.—This class of soil is not of great importance, first because of its small area and its inaccessibility, and secondly because it is usually a coarse, loose soil, rather unfavourable for plant growth. It is formed, as its name indicates, in regions of precipitous topography, and is made up of fragments of rocks detached from the heights above and carried down the slopes by gravity. Talus slopes, cliff debris, and other heterogeneous rock detritus are examples of colluvial soil. Arranged as made up largely of rock material. As the physical forces of weathering are least active in the formation of these soils, the amount of solution and oxidation is small. The upper part of the accumulation

¹ Kerr, W. G. *Geology of North Carolina*, Vol. I, p. 785, 1908.

reflects the isolated physical action to the greatest extent, the particles being angular, coarse, and compositionally fresh; farther down the slope the material may merge by degrees into ordinary soil. Such soils are usually shallow and stony, and approach the original rock in color unless large amounts of organic matter have accumulated (Fig. 5).



FIG. 5.—Diagram showing the formation of a colluvial soil: (A) bed rock; (B) disintegrated; (C) coarse representation; (D) soil composed of loosely packed.

3. Alluvial soils.—In considering the importance of water as a weathering agent, it was found that it had both eroding and transporting powers. The alluvial

will is a direct result of both these activities. The carrying power of water varies directly to the fifth power of its velocity; so that a doubling of the velocity increases the transportive ability sixty-four times. It is estimated¹ that water flowing at the rate of three inches a second will carry only five clay, but if this rate is increased to twenty-four inches a second, pebbles the size of an egg will be moved along the stream bed. Any doubling of the velocity of a stream will cause it to deposit the material carried in suspension, the larger particles first and the finest when the current becomes very sluggish. This brings about one of the important characteristics of an alluvial soil, its stratification. Whenever material is being laid down by water this phenomenon is exhibited, due to the rapid changes in velocity. As a stream approaches a corner and comes to its outlet, its bed becomes then and less inclined and the current more and more sluggish. This tends toward aggrading of the stream bottom from the deposited material. Such a condition naturally increases the probability of overflow in high water. Overflow at a time when the stream is carrying its maximum of sediment causes the deposition of a thin layer of soil over the areas covered by the water. This soil is stratified according to the conditions under which it was laid down, the finer particles usually being carried farther and when deposited in thick water or lagoons. Also, a stream on a gently inclined bed may begin to curve from side to side in long, gentle curves, due to the deposition of alluvial material on the inside of the curve and the eating by the current on the opposite bank. This results in ridges, lagoons, and similar features,

¹ Odell, A. *Text Book of Geology*, p. 360. New York, 1928.

tial for the deposition of alluvial matter. Below are another good example of alluvial deposits, whether covering an ocean, gulf, or lake. Due to a change in grade, a stream may cut down through its already well-formed alluvial deposit, leaving terraces on one or both sides. Often two, or even three, terraces may be detected along a valley, marking a time when the stream bed was at those elevations. On the lower slopes of hills bordering valleys, the alluvial deposits may touch or even merge with the alluvial, and furnish a stream with some of its siltation.

Alluvial soils, then, are found on narrow ridges along streams. They are always young soils, and are still in process of becoming. Some in most cases they are deposited by slowly moving water, the texture of such soils is fine, the soils being mostly clays, silts, and fine sandy loams. Found in low lands, alluvial soils need drainage to a large extent. Because of the favorable conditions under which these soils usually have a very large amount of organic material, or vegetation grows readily under such conditions. *Crematula* boron is also washed into alluvial materials at the time of their deposition. The soil is usually very acid, because of the high organic content, testimony of great physical condition, although very heavy stiff clays may be found in certain cases. The character of the soils and the order from which the *Arctia* has been obtained exerts considerable influence on its character. For example, a red soil will often give rise to a reddish alluvial soil, while a soil of a pink pore in time will certainly not be passed to a soil very much richer in that constituent.

IX. *Distribution of alluvial soils.*—The distribution of alluvial soils in the United States is not wide, although

these wilds exist along almost every stream east of the Great Plains Region. Their best and widest development is found, as the map indicates (See Fig. 3), along the lower Mississippi River, where they may often show a lateral extension of one hundred miles. Extension of this kind was noted along the Missouri, Ohio, and Upper Mississippi rivers. All streams showing most striking areas of such wilds, these areas varying with the size and velocity of the stream.

The wilds of the alluvial provinces may be divided under two heads because of topographic differences—(1) the first bottom, or present flood plain; and (2) the terraces, or old flood plains. These wilds differ in their abundance, drainage, and age, but their general characteristics are similar; the surface features in both cases vary from a flat to a gently rising topography (Fig. 6). Drainage, especially in the terraces, may have obliterated some of the old



FIG. 3.—Connection of lateral alluvial soil. (A), bed soil; (B), terrace; (C), stream bed; (D), stream bed; (E), stream bed; (F), stream bed; (G), stream bed; (H), stream bed; (I), stream bed; (J), stream bed; (K), stream bed; (L), stream bed; (M), stream bed; (N), stream bed; (O), stream bed; (P), stream bed; (Q), stream bed; (R), stream bed; (S), stream bed; (T), stream bed; (U), stream bed; (V), stream bed; (W), stream bed; (X), stream bed; (Y), stream bed; (Z), stream bed.

standing features. Alluvial soils, being very rich, are particularly adapted to trucking crops, although in most cases they are utilized for more extensive farming. When well drained and protected from overuse, they are the richest and most valuable of soils.

31. *Machine soils*.—The sediments which are continually being carried away by rivers are eventually deposited in the sea, the coarser fragments near the shore, the finer particles at considerable distances. This layer of material, varying in thickness, consists of stratified gravels, sands, and clays, and is of a rather recent age compared with the residual soils. It has not become consolidated as yet, because of insufficient pressure and time. When such material becomes raised above the sea, due to a change in land elevation, it is classified as a *machine soil*. It has been worn and fragmented by a number of agencies. First, the forces necessary to throw it into stream transportation were acting, and next it was swept into the ocean to be deposited and stratified, possibly after being pounded and eroded by the waves for years. At last, came the emergence above the sea and the action of the forces of weathering in this. The latter effects are not of great account, since with our most important machine soils they have been at work for but a comparatively short time, speaking geologically.

32. *Characteristics of machine soils*.—Machine soils, while much younger than residual soils, are usually more firm and uniformly show a less amount of the important food elements. This is because of their almost continuous contact with water from the time when they are swept into the streams until they rise above the sea level in a soil. They are generally characterized as sandy soils, because the forces to which they have been subjected have worn out and dissolved more of the material except quartz. This gives them a coarse texture and fits them particularly for tramping soils. Sands, sandy loams, and loams predominate usually in sand, and gravels, although clays and silts may occasionally be

found. These soils are usually low in humus, and consequently must be handled with reference to the possibilities of increasing their organic content. Lack of humus makes the predominating color of the soil light, ranging from light gray to brown and dark brown. The character of these soils is general to some extent by the origin of the sediments; different rocks, particularly if weathered under different climatic conditions, may give rise to widely different marine soils. The climatic conditions to which marine materials are subjected after being mixed above the sea may also be a considerable diversifying agency.

32. Distribution of marine soils.—Marine soils are found very widely distributed in the eastern United States, and make up one of our most important soil provinces. Beginning at Long Island at the north (See Fig. 4), they extend southward along the coast in a band ranging from one hundred to two hundred miles in width. The western edge of the Atlantic coastal plain is marked by the great "Fall" line, or the edge of the old continental Appalachians. It is from this area that most of the soils across the Atlantic marine soils were derived. Proceeding southward, we find that Florida is practically all of marine origin, together with a great area of the Gulf coast extending westward to central Texas and having an average width of two hundred fifty miles. This gulf marine soil is considerably younger than that of the Atlantic coast. It is cut into two parts by the alluvial soils of the Mississippi, and is covered by a narrow band of alluvial soil on the eastern bank of that stream. The sediments of the Gulf coastal plain were derived from the erosion and denudation of the old lands to the northwest.

The soils of the Atlantic and Gulf coastal provinces, found in most extreme places, are very diversified, due to power of material age, and climatic conditions. They comprise a sufficient range in texture and climate to support a highly varied agriculture. There are great areas of general farming land, besides rich areas of special purpose soils adapted to highly specialized industries. The latter soils require unusual and intensive methods of cultivation. Traditionally sandy, these soils are easy to cultivate, and they are well drained except in the lower coastal plain belt. Good drainage is usually found because of their one-directional condition. Severe leaching occurs in places of heavy rainfall, for the same reason. When sufficiently supplied with organic matter, carefully fertilized, and cultivated properly, these soils support a great variety of crops, such as cotton, corn, oats, forage crops, and peanuts, besides vegetables and kinds of many varieties.

CHAPTER IV

GEOLOGICAL CLASSIFICATION OF SOILS (Continued)

Ice in the form of glaciers has been, as already stated, a very great factor in soil formation, especially in the north temperate zones of North America, Europe, and Asia. Not only was the old mantle of material swept from the land by the advance of the ice, but it was also was laid down as drift material. This drift was sometimes merely ground-up rock, sometimes sand flour mixed with the original residual soil, and sometimes glacial material wholly composed and considerably protected by water. Besides this, the stresses of water that issued from under the glaciers were instrumental in many cases in distributing sediments; a considerable number of lakes and swamps of the ice front. Glacial lakes, also, when in existence for sufficiently long periods, furnished means for the distribution and deposition of materials derived from the erosive and grinding power of the ice. The ice also furnished a large amount of very fine detritus, which was susceptible to wind movement. This material, mixed and deposited as has been shown here, was carried many miles by the prevailing westerly winds during a period of stability following the glacial epoch. It was blown over wide areas, especially in the Middle West of the United States and in northern China, in which places it reaches its best development.

is the important soil of these regions. Glaciation was fundamental, then, either directly or indirectly, in the formation of these general classes of materials—glacial drifts, glacial lake soils, and a certain class of fluvial materials deposited on bare and white.

31. The ice sheet!—If in any region, but more likely one of more elevation, the temperature and the annual snow in such relationship that the heat of summer does not offset the winter accumulation of snow, great snow fields form. As this condition persists year after year, and the snow becomes deeper and more widely spread, the temperature is reduced to such an extent as to increase the proportion of the precipitation which penetrates through the stream's bed. The pressure of the overlying snow, and the water from the melting surface, bring about a change of the snow into ice. Often a recrystallization appears to occur followed by melting and refreezing. As the depth of ice increases, the phenomenon of movement is inaugurated on the surface of the ice at the outer developing lateral pressure. Ice, when under great stress, exhibits a plasticity which it does not ordinarily possess. As it moves slowly forward under the increasing pressure, and with a thickness of development almost incredible, it continues itself to every extremity of the surface it may be reaching. It rises over hills or shapes itself to valleys and even small depressions, with requiring ease. The rate of advance or retreat of a glacier is determined by the rate at which its edges are wearing or melting away. If the melting is slow, the ice flows advance; if it just balances the advance, the

¹For a complete discussion of glaciers and glaciation, see S. W. Wothers, U. S. The Glacial Country of New Jersey. U. S. Survey of New Jersey, Vol. 3, 1903.

ice front is at a standstill; but if the melting is rapid, and the advance of the glacier is not fast enough to replace this waste, the ice is said to be retreating. A great ice sheet may exhibit all three of these conditions many times in its history.

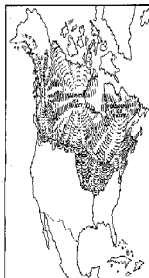


Fig. 1.—Map of North America, showing the area covered by the great ice sheets, the lines marking the retreat of the ice, and the approximate position of the ice front.

At the American ice sheet. The northern part of the American continent was at one time covered by a

great sheet of ice possessing all the properties described above. Accumulation seems to have occurred in three well-defined centres, from which, over long geologic periods, the ice slowly moved southward, encroaching upon and covering thousands of square miles. The ice cap of Greenland is a very good example of the conditions thus existing in the northern part of the United States. The area covered by glaciers in North America at the time of the greatest extension of the ice is estimated as 4,000,000 square miles. The thickness of the sheet was probably very great, varying from a few feet at the margin to probably a mile or more toward the center; or, at least it was thick enough to overlie some of the highest mountains of the New England region. Local glacialides also occurred on the hill and mountain tops, which tended to increase the apparent coldness of the ice masses.

11. *Causes of the ice ages.*—The ice ages was not one continuous invasion and retreat of the ice cap, but was, as it is recorded by all authorities in glacialism, really divided into epochs. Five great invasions appear to affect at least the central part of the United States, possibly without bringing about a disappearance of the ice across the Canadian border. These interglacial periods are shown by forest beds, accumulations of organic matter, and evidences of contact between the drift deposited by the successive ice sheets. Some of the interglacial periods evidently were times of warm, and even sub-tropical, climate. Just exactly what was the cause of the ice ages is still under dispute. The most probable theory, both as to its occurrence and as to its disappearance, is that a change in the actual climatic content of the atmosphere took place. It is believed

that doubling the amount now present would bring about tropical climates in the temperate zones, while holding it would cause high mountains and a probable return of the great ice fields.

37 The extension of the ice sheet.—While the advancing ice in general exhibited well-defined variety, certain parts were more or less rigid. This was especially true of the parts near the edges of the sheet. These parts had become filled in their advance, particularly near the bottom, with earthy and stony material, which aided the erosive processes to a very great degree. The cooling and denuding power of the glaciers is shown everywhere by the gouged-out valleys and by the scorching, or strie, on exposed rocks. As this sheet of ice slowly advanced a few inches or a few feet a day, the surface of residual soil was carried away or mixed with the rock from constantly formed by the moving ice. The original soil was really an instrument for more effective its action. The scouring effect is observed now to the best advantage in valleys which by longitudes in the ice movement, as all the valleys of the Finger Lakes of central New York. Valleys lying at right angles to the ice were very often partially or wholly filled with debris, and the entire topography was altered. Rivers flowing under the ice often left large amounts of materials designated now as ridges and kames. The mining, grinding, transporting, and distribution that went on everywhere upon the great influence of glaciation on general topography and soils.

The greatest accelerated extension of the ice to the United States is marked by a great terminal moraine (Fig. 8). It is supposed that the margin of the sheet was stationary at this point for a sufficiently long period to allow the

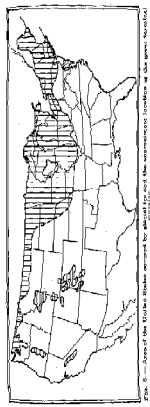


FIG. 6.—Areas of the United States occupied by the subgenera of the genus 'Tribes of the genus'.

surface band of material to collect by the seasonal melting of the ice and a consequent dropping of its load of debris. This remains so by no means continuous, and for miles across the continent so true of it can be found. It certainly, roughly, radiates from the Canadian border in Washington to the upper waters of the Missouri River, then down that river to St. Louis, up the Ohio River, northwardward until the northern border of New York is reached, and then southeast to New York City and Long Island. Many other meanders are found to the northwest, marking points where the ice became stationary for a time during its retreat.

All the ice is a *net holder*. . . . It was during these periods that the ice acted as a *welding agent*. Material gathered and ground by the ice as it pushed to the southwest was finely pulverized and it is only natural to suppose that this debris was deposited as the ice slowly retreated by the melting back of its margins. The material laid down as a great mantle over the glacial *erosion* is called *drift*. Some of this has been eroded and stratified by water, but a very large proportion has remained unstratified since it was laid down by the retreating ice. It presents in most cases—except at the very surface, where *weathering* may have occurred or organic matter accumulated—exactly the same condition as when deposited. This mass of unstratified material is heterogeneous, both as to size of the particles that make it up and as to its rock composition. It may be coarse and bouldery, especially in sandstone or where there are gravels or schists, or it may be very fine where the rocks are soft. Boulder clay is a term sometimes used in describing the matrix of this glacial deposit. In some cases *clotting* occurs, and other coarse and fine layers

of ill may alternate. This great mass of material, varying in thickness and constitution according to the underlying rocks and the strength of pluviation, gives a great soil province in western United States which may be designated as glacial till soil.

39. *Glacial till soils.* The glacial till soils may be characterized physically as heavy or relatively heavy soils. The tremendous force of the grinding has produced fine particles, soil as a consequence clay loam and silt loam predominates. Such soils usually have a color which is finer than the surface material and may be so impervious to water as to produce bad drainage conditions. The individual particles of a glacial soil are found to be crumpled in a great degree unless the soil is mixed with some of the old mass of residual material which once covered all our glacial areas. The particles are jagged and angular; the fissures retain all of their water, and the iron stains so common in residual soils are absent almost. As the glacial soils are young soils, their colors are rather much as if red and yellow, but gray and brown prevail. But may come, however, where red sandstones have been pluviated or where red residual soil has become incorporated in the till. When considerable organic matter has accumulated the soil is usually very black. The subsoils in the glacialized areas usually present colors ranging from light gray to light brown. Blue or mottled clay or clay loam is often found, due to a lack of aeration in the soil; to the soil expert such a condition near the surface indicates a root of drainage.

40. *Composition of glacial soils.* The chemical composition of glacial soil approaches more nearly than that of any other soil the composition of the original rock.

This close resemblance to the parent rock is not surprising, since glacial soil is parent-up rock, material of recent formation on which the modifying agencies have as yet had little time for action. Therefore the movement of the important constituents in such soil are governed largely by the composition of the original rock. The fine content is due to such a relatively, and the agricultural value of the soil is greatly influenced thereby, since large amounts of silicates are of great importance to soil fertility. The hill soils of central New York (Tillman series) come from shales poor in lime, and the soil owns its properties very largely to this lack, which is traceable to the parent rock. On the other hand, certain glacial soils of the Mississippi Valley (Harris series) formed from sandstones and limestones, contain plenty of lime due to the nature of their rock origin. Glacial soils from limestone always contain plenty of lime, a condition that is far from true with residual soils.

41. *Humus of glacial soils.*—The humus content of glacial soils depends to a large extent on the climatic conditions under which the soil has existed since its formation. If periglacial factors have been such as to encourage the accumulation of organic matter, these soils will exhibit the deep black color that arises from the presence of such material. If, however, conditions do not encourage the natural growth of luxuriant vegetation, the amount of organic matter in such virgin soil will be low. There may be a very great factor in such soils, not only in the encouragement of plant growth, but also in the proper decay of the plant tissue after it has become incorporated with the soil.

Glacial till soils are found distributed over all the area north of the great terminal moraine, and generally, roughly,

from New England to the Pacific coast (see Fig. 4). They comprise a great variety of soils, not only as to their physical character, but also as to fertility. They are adapted to many crops, but general fertility is provided as often to the greatest degree. This means extensive, rather than intensive, agriculture. In some localities dairying has been developed to a large extent, and has proved to be not only a means of obtaining paying returns from such soils, but at the same time a method of keeping up their fertility.

43. *Glacial lakes*.—Such great masses of ice could not advance and retreat, again and again, on such an extensive scale, without causing the formation of great torrents of water. It is more than probable that at all times great streams gushed from the ice front, laden with much sediment. Often these streams were under pressure, which when released caused an immediate deposition of material. As long as the ice front stood south of the east and west divide, this water faced ready escape and flowed rapidly away to deposit its load as gravelly material, river terraces, valley trains, and alluvial fans. These formed alluvial soils of varied character, depending on the size of the materials carried. There came a time, however, in the retreat of the ice, when the front stood north of the divide and only a small proportion of the water found itself free to flow over the divide and away to the southwest. The remaining water was trapped between the ice front and the old divide. Then closed lakes were produced, of large or small extent, according to the position of the ice. The location of such lakes is shown on the soil map of the United States. The perched water remained in this position for many years subject, of course, to changes consequent with

the melting of the ice front. With the ice melting rapidly on the hillsides, these lakes were constantly fed by torrents from above which were laden with sediment derived not only from under the ice, but also from the unconsolidated alluvium over which it flowed. As a consequence, there were in the glacial lake deposits ranging from coarse delta materials near the shore to fine silt and clay in the deeper and stiller water. Such materials now cover large areas (see Fig. 4), not only in New York State and along the Great Lakes, but also in the Great River Valley and in the similarly isolated valleys of the Rocky Mountains and the Cascade and Sierra Nevada. They make up by far the most important lacustrine soils.

63. *Lacustrine soils—glacial lakes.*—Glacial lake soils probably present as wide a variation in physical characteristics as any of our great soil provinces. Being deposited by water, they have been subject to much sorting and stratification, and range from coarse gravels on the one hand to fine clays on the other. They are generally found as the lacustrine soils in any region, although they may occur well up on the hillsides if the shores of the old lakes extended thus far. The color of such soils varies from gray to black, according to the degree of organic matter present. The texture content of such soils, as with the glacial till, varies with climate and may be high, low, or medium according to conditions. The thickness of glacial lake deposits is variable, ranging from a few feet to many feet. Its chemical composition they closely approximate the soil from which they are derived. This is particularly true as regards the presence of lime. The Dunkirk soil of southern New York, a wash from the limy glacial

Volcanic series of the highlands is low in lime; while the same soil just south of Lake Ontario, obtaining its wash from a limestone till (Hudson series), is rich in lime. As may be inferred from the above comparison, the glacial lake soils of the United States are variable in their fertility.

The distribution of the glacial lake deposits, as seen from the soil map of the United States, is fairly wide. Such soils are found in areas large enough to be of great agricultural importance, extending from New England westward along the Great Lakes until their greatest exposure is reached in the Red River Valley. These deposits make up some of the most important soils of the northern states. They are valuable not only for extensive cropping with grain and hay, but also for fruit and trucking crops. The low slope was certainly not in view as far as the production of fertile soils is concerned.

46. *Lacustrine soils—recent lake.*—There is yet another lacustrine soil to be considered, besides the one just discussed—recent lake soil. While the glacial lake deposits were formed many thousands of years ago, the lake soils of the second group are in process of formation. It is a well-known fact in physical geography that lakes are only enlarged stream beds, and are destined ultimately to be filled by river sediments. Such soils have been restricted to a certain extent, but their average is not large enough to give them the importance of the glacial lake soils. The lake soil is usually of a fine character, rich in humus, of good tilth. If properly drained, it is almost invariably highly productive, and is adapted to a variety of crops depending on climatic conditions.

45. *Glacial soils.*— During glacial time much fine material was carried miles below the front of the glacier by streams that found their source therein. With the retreat of the ice the material was deposited over wide areas by the overhauled rivers. The accumulations occurred below the ice front at all points, but seem to have reached their greatest development in what is now the Missouri Valley. There, too, the sediment seemed finest, and, coming mainly from glacial floestones, was very rich in calcareous. It is generally agreed by glacialists that a period of stability, at least as far as this particular region is concerned, immediately followed the retreat of the ice. The low rainfall of this period was accompanied by strong westerly winds. These winds, acting perhaps through canyons, were instrumental in the picking-up and distributing of this fine material over wide areas of the Mississippi, Ohio, and Missouri valleys. One strong argument for the Asian origin of this fine soil is found in the *Aegagropis* and *maui* *diarrhizoides* development along the eastern banks of the large streams. Especially noticeable is the extension down the eastern side of the Mississippi River almost to the Gulf of Mexico. This wind-blown material, called loess, is found over wide areas in the United States, in most cases covering the original till marks. It covers eastern Nebraska and Kansas, southern and central Iowa and Illinois, western Missouri, and parts of Ohio and Indiana, besides a wide band, as already noted, extending southward along the eastern banks of the Mississippi River. Due to its mode of origin, its depth is always greatest near the source and gradually becomes less farther inland. In places, notably along the Missouri and Mississippi rivers, its accumulation has given rise to great bluffs which

believe a characteristic topography to that region. The loess soil is found also covering the great areas of China and Siberia, and thus it is one of the important soils of the world. Another soil, made up, at least partially, of wind-blown material and found in Arizona and New Mexico, is called *adobe*. Volcanic soils of the western United States and elsewhere are to some extent of wind origin. Good times are of *Redina* origin, but these soils are insignificant as to agricultural value when compared with the soil natural clays, especially loess.

41. Loess soils.—Loess is usually a fine calcareous silty or clay, of a yellowish or yellowish buff color. While it may be readily pulverized when subjected to cultivation, it possesses remarkable tenacity in resisting ordinary weathering. The vertical walls and escarpments formed by this soil show one of its striking physical characteristics. In China¹ caves that house thousands of persons are dug in the cliffs and columns existing in this deposit. Another feature of loess is the presence of minute vertical crack-like lines with a deposit of calcareous nodules. These cracks are supposed to give the soil its vertical cleavage and its tenacity. The particles of loess are usually unweathered and angular. Quartz seems to predominate, but large quantities of feldspar, mica, hornblende, augite, calcite, and other minerals are found.

A few typical analyses² are given below:

¹Smithson, F. *Chinese Loess*. *Trans. Roy. Soc.*, 1892, p. 392.

²Clark, F. W. "The Data of Classification." *U. S. Geol. Survey, Bul. 411*, p. 492. 1911.

A. *Pruss and Delaware, Texas.*

B. *From Fairbury, Minnesota.*

C. *From Kansas City, Missouri.*

D. *From Cheyenne, Wyoming.*

| | A | B | C | D |
|--|-------|-------|-------|-------|
| SiO ₂ | 73.98 | 69.95 | 76.45 | 67.41 |
| Al ₂ O ₃ | 12.96 | 7.56 | 12.25 | 9.38 |
| FeO ¹ | 2.76 | 2.05 | 2.25 | 2.52 |
| MgO | 1.11 | 4.35 | 1.15 | 1.55 |
| CaO | 1.50 | 8.95 | 1.65 | 2.08 |
| Na ₂ O | 1.85 | 1.17 | 1.41 | 1.62 |
| Li ₂ O | 2.12 | 1.08 | 1.65 | 1.68 |
| TiO ₂ | .35 | .18 | .06 | .11 |
| Cr ₂ O ₃ | .30 | 1.94 | .46 | 2.07 |
| Ta ₂ O ₅ | 2.83 | 1.14 | 2.70 | 1.09 |

It is immediately noticeable that the lime content of these soils is high, as is also the phosphoric acid. In fact, all the more soluble constituents are present in relatively large quantities, as would naturally be expected from the mode of origin of such soils—they having been subjected to acidity and then deposited by the wind at a relatively recent period. It is maintained by some geologists¹ that the deposition of loess is still going on in certain portions of the world, but that the rate of accumulation is so exceedingly slow that it escapes the notice of all but trained observers. The lack of fossils, particularly those of plants, is accounted for by the slow rate of formation, which allows sufficient time for all organic matter to become fully oxidized before being covered by the drifting material. Shell shells are often found, but as they are of land species they appear against a water-worn or loess.

¹ Kienbohn, *U. The Question of the Origin of Loess*. With *Julius Perkin's* *Geog. Anal.*, 56, pp. 33-42, 34-74, and 120-130, 1913.

37. *Distribution of loess.*—Not only is loess found over thousands of square miles in the central part of the United States, but it occurs elsewhere in large areas. It is greatly developed in northern France and Belgium, and along the Rhine in Germany, where it is an important soil in all the valleys that are tributary to that river. Russia, Poland, southern Russia, Siam, Hungary, and Germany, all have deposits of this highly fertile material. In Europe it extends from sea level to elevations of 5000 feet, showing its independence of water as a formative agent. In China it is found over a very large part of the valley of the Huangho, a region probably larger in area than France and Germany combined. The thickness of the deposit is variable, ranging from a few feet to several thousand feet in certain places. The depth is practically always sufficient for any form of agricultural operations.

Wherever modern relations are favorable loess is an exceedingly fertile soil, due to its rich mass of potash, phosphorus, and lime. Its surface contour is usually regular to high, depending on conditions. In general it may be classified as the richest soil in the world, considering its wide extension and the great variety of climate and of crops to which it is subjected. In the United States it occurs in the Corn Belt region, and might be called the great corn soil of the Mississippi Valley.

38. *Adobe soils.*—The term *adobe* is a name applied to a fine ochraceous clay or silt loam in a manner somewhat like that in which loess is treated. It is supposed that, while part of the deposit came from the waste of lake depressions, the remainder was reworked under conditions of aridity; the remainder had an origin similar to that of

less? Certain characteristics also seem to indicate that the valley soils might have been deposited by water? It appears, therefore, that, while the physical characters of all soils are somewhat similar, its mode of origin and chemical composition may be variable. Below are the analyses¹ of two typical valley soils:—

| | A. | B. |
|--|-------|-------|
| SiO ₂ | 60.00 | 66.64 |
| Al ₂ O ₃ | 16.96 | 12.55 |
| Fe ₂ O ₃ | 5.30 | 5.12 |
| CaO | 2.89 | 12.03 |
| MgO | 1.20 | 2.85 |
| K ₂ O | 1.51 | 1.23 |
| Na ₂ O | .67 | .60 |
| Cl ₂ | .77 | 8.05 |
| P ₂ O ₅ | .30 | .08 |
| Organic matter | 7.00 | 3.62 |

Like the loess, alluvial soil is an everywhere rich soil, but it occurs in an arid or a semiarid region. When irrigated, its fertility seems incalculable. It is found in Colorado, Utah, western California, Arizona, New Mexico, and Texas. It has an especially wide distribution in New Mexico. Like loess its elevation is variable, ranging from sea level in California and Arizona to 6000 feet along the eastern border of the Rocky Mountains. Its maximum thickness cannot be estimated, as it is very

¹ Russell, J. C. *Salinized Soils of the Arid Regions of North America*. *Chem. Mag. Amer.* 1906, 35, 242-250.

² Gilbert, H. W. *Reclamation of Soil to Climate*. U. S. Weather Bur. Bul. 1. 1902.

³ Merrill, G. P. *Soils, Their Weathering, and Origin*, p. 321. New York. 1905.

little eroded sand is supposed to be still accumulating. Some valleys are known to be filled to a depth of 2000 feet with this material. Its characteristics are its fine texture, its great depth, its wide distribution, and its great fertility when moisture conditions are suitable for crop growth.

40. *Seed dunes.* Seed dunes are the outgrowth of two conditions—a large quantity of seed and a wind that blows in a more or less prevailing direction. Under such conditions the sand and other fine material not only is blown into heaps, but also tends to move in the direction of the prevailing wind. North winds or winds of sand may blow several feet a day by the vertical movement of the sand grains up the windward side of the dune, only to be deposited again on the leeward side. Seed dunes may often assume gigantic proportions, being sometimes several hundred feet high and twenty or thirty miles long. In such proportions they become a grave menace to agriculture, not only because they are an absolutely valueless medium for plant growth, but also because they cover fertile lands and entirely shut out all plant growth. The particles of the wind-blown sand are usually round, from the continual abrasion that they receive. A great many minerals may be represented, but quartz is the commonest, especially if the sand originally had its origin on a lake or shoreline.

41. *Volcanic dust.*—From early preglacial times deposits of the very fine material that is continually being ejected from volcanoes have been distributed over the world's surface. These deposits are easily denuded, and while at one time they probably covered many square miles of territory, they have succumbed very

largely its origin and distribution, and only remnants are found at the present time. Such material may be found in Montana, Nebraska, and Kansas. Molau deposits of this character are usually rather porous and light, and are likely to be highly siliceous. They are not of great agricultural importance.

CHAPTER 9

CLIMATE AND GEOCHEMICAL RELATION- SHIPS OF SOILS

Attempts to reach the process of weathering the tendency of all soil to trend to certain composition, such a condition is never reached, due to different kinds and varying intensities of decay and disintegration. Soil kind therefore readily is a geological classification because of this difference in mode of formation. Such a classification really signifies a variation in composition. A difference in age, a preponderance of physical agencies over chemical or vice versa, a difference in the temperature agencies, or a variation in climatic conditions after a soil is once formed will necessarily give a different product, not only chemically, but physically and biologically as well.

16. *Climatic relationships.* It is evident that climate is a factor in all geochemical relationships of soils. Not only does climate determine the kind of weathering and its intensity, but in many ways it influences very largely the characteristics of the soils of different provinces and regions. Climate must be considered also in the geological classification of soils, since it plays much to its part in determining the kind and intensity of the formation agents. In any scheme of grouping for the systematic survey and mapping of soils, climate is the very first factor to be considered. It gives three great groups: tropical, subtropical, and temperate. These may in turn be subdivided into arid, semiarid, and humid.

In the selection of soil, climate, particularly as regards rainfall and temperature, plays an important part. Crop adaptation is really more of an adaptation to climate than to soil, although the latter also should be very carefully studied. The climatic relationships in soil formation, its soil chemistry, and its geobotany in general, cannot be too strongly emphasized, whether the viewpoint be technical, practical, or merely educational.

15. *Geobotanical relationships of residual and residual soils*. — It is evident from the above that residual, residual, and glacial soils should exhibit certain well-defined general differences due to their mode of formation. The following analyses, which are representative of the processes in question, illustrate the chemical differences of residual soils and residual soils:—

ANALYSES OF TYPICAL CALICHE FLOES AND RESIDUAL SOILS.

| | Caliche (from the surface) | Caliche (from the surface) | Caliche (from the surface) | Caliche (from the surface) |
|--|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| | Caliche (from the surface) | Caliche (from the surface) | Caliche (from the surface) | Caliche (from the surface) |
| SiO ₂ | 80.50 | 80.55 | 81.51 | 81.57 |
| Al ₂ O ₃ | 12.20 | 12.22 | 12.55 | 12.46 |
| Fe ₂ O ₃ | 2.11 | 2.15 | 2.16 | 2.15 |
| MgO | 2.05 | 2.05 | 2.05 | 2.05 |
| CaO | 4.1 | 4.2 | 4.20 | 4.2 |
| Na ₂ O | 1.6 | 1.6 | 1.60 | 1.6 |
| K ₂ O | 1.0 | 1.0 | 1.0 | 1.0 |
| Total | 100 | 100 | 100 | 100 |

¹ Voth, H. F. The Chemical Composition of Maryland Soils. Maryland Agr. Exp. Sta., Bul. 16, pp. 71 and 79, 1914.
² Merrill, O. P. Weathering of Mesozoic Granitic Rocks, County, Virginia. *Int. Geol. Soc. Trans.*, Vol. 4, p. 100, 1891.
³ Voth, H. F. The Chemical Composition of Soils. *Soils*, T. R. Co. Survey, Bul. 136, p. 285, 1908.

It is to be noted, in the first place, that silica tends to large quantities in the residual rocks, due to the fact that quartz is such a resistant mineral. The constant finding that this cell has *retrograde* has very largely determined the silicates. The aluminates and oxides are rather low in the average in such rocks, even in those of the diorite type. It is to be noted also that the amounts of phosphoric acid, calcium, potash, magnesia, and sodium are much less in the mafic rocks, due to the caustic washing that they have received. These figures would tend to the belief that in general the mafic rocks are lower in the mineral *fluorides* than the rocks formed in situ. The amount of aqueous matter that they may contain depends entirely on their location and climatic conditions. They may or may not be rich in *halogens*, according to circumstances. It is generally considered, however, that they are not so well supplied with the aqueous elements as are other rocks.

8. Metased and glacial rocks.—A comparison of metased and glacial processes cannot be made with such assurance, because of the many kinds of rocks that may have been parent to the rocks and because of the great variety of climatic conditions under which the *weathering* processes may have gone on. Such a comparison is best made in a region where both *metased* and glacial rocks are found, as ready as it is possible to judge, coming from the same rocks. Analyses of rocks under such conditions are available from the *Chibougamau* and glacialized parts of *Manitoba*. The original rock was limestone. The analyses¹ are as follows:—

¹Chibougamau, T. G. and Salisbury, H. D. The *limestone* area of the Upper Mississippi. *Trans. Am. Mus. Nat. Hist.*, N. S. Vol. Twenty, pp. 280-290. 1905.

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**ANALYSIS OF SUBSOL AND PLURAL CLAYS FROM THE DUFF-
1228 AND CLAYTON FARMS OF WISCONSIN**

| | BROWN | | CLAYTON | |
|--|-------|-------|---------|-------|
| | 1 | 2 | 3 | 4 |
| H ₂ O | 25.13 | 26.12 | 49.22 | 48.81 |
| Al ₂ O ₃ | 12.10 | 9.07 | 8.47 | 7.54 |
| FeO ₂ | 5.35 | 11.04 | 5.97 | 3.51 |
| MgO | .20 | 1.20 | 7.50 | 7.55 |
| CaO | .45 | 1.90 | 15.55 | 11.85 |
| MnO | 2.39 | 1.51 | .98 | .82 |
| SiO ₂ | 1.11 | 1.18 | 2.19 | 2.00 |
| Li ₂ O | .40 | .04 | .05 | .25 |
| CO ₂ | .43 | .20 | 18.75 | 14.17 |
| SiO ₂ | 6.61 | 11.72 | 1.85 | 2.01 |

These analyses illustrate to very good advantage the points indicated by Chamberlain and Salisbury regarding the difference between residual and plural clays. Residual clay is designated by them as "red soil," and plural clay as "red fine." The latter, having been weathered, contains a larger proportion of its easily soluble materials. It is to be noted here, as in the comparison of native and residual soils, that silica, aluminum, and iron are lower in the soil subjected to the less amount of leaching, which in this case is the plural clay. This in itself would serve to indicate that the important plant-food constituents are generally present in larger quantities in the plural clay. In fact, it would be expected that the plural soils would approximate very closely the red or rock from which they came. The phosphoric acid, lime, sodium, magnesium, and potash of the residual soils in this case amount on the average to 5.77 per cent, while that of the plural clays reaches the high figure of 26.81 per cent. This is due largely to the great amount

if these present, and again emphasizes the point that, while a glacial soil from a tundra in 1916 is fine, a residual soil from the same rock is usually poor in that respect. These loess, which has been subjected to some eroding before being deposited, is a considerably richer soil than those of residual origin.

It must be remembered, however, that these comparisons are of a general character and do not apply to all cases, since many glacial soils may be very much poorer in the glacial constituents than some of the representative residual soils. Moreover, the physical condition of a soil is a great factor in productivity. As a matter of fact, the mere presence of glacialloids is but one of a considerable number of factors that determine the crop-producing power of a soil. Also, the human material of the soils of various provinces may be variable, due to climatic conditions. Neither are all glacial soils rich in loess, so that abundance is determined largely by the amount in the parent materials. A rich poor in loess, therefore, must have recently given rise, when glacialized, to a soil deficient in loess. This is well illustrated by the average analyses¹ of the loess soils of Adirondack County, Ohio, originating from the glacialization of the two-poor shale of that region:—

| | |
|---|------|
| CaO | 35 |
| MgO | 51 |
| P ₂ O ₅ | 90 |
| K ₂ O | 1.87 |
| N | .15 |
| Humus | 1.20 |

¹ Jones, J. P., and Wallace, R. W. Soil Investigations. Ohio Geol. Surv. Div., Vol. 20C, 1913.

However, our major premise does seem to stand in a general way—that a glacial soil, other things being equal, contains a larger amount of the mineral plant-food constituents, and, obviously a smaller amount of such materials as silica, iron, and aluminum, than does a corresponding soil of residual origin.

The following data¹ bring out the points already dealt with in their fullest significance:

Phosphorus in FeO , CaO , MgO , and H_2O in Heat or Distillate Phosphates

| Heat | FeO | CaO | MgO | H_2O |
|------------------------------|--------------|--------------|--------------|----------------------|
| ? (United States) | 107 | 24 | 34 | 1.17 |
| 3 (United States) | 35 | 107 | 15 | 2.03 |
| 10 (United States) | 32 | 7.23 | 19 | 4.95 |

4. *Effect of glacial soil on agriculture.*—These differences between residual and glacial soils reflect on the general fertility of the soils. In a comparison of the fertilizer uses of Wisconsin with the glacial parts² only 55 per cent of the former is supposed as against 84 per cent of the latter, while the value of the farms on the glacial soil averages 50 per cent higher. The more general differences appear between the glacial and residual soils of Indiana³ and Ohio.⁴

¹ Bailey, O. H., and others. *The Mineral Composition of Soil Products*. U. S. D. A., Bur. Soil, Bul. 56, 1905.

² Fritchett, R. H. "The Glacial and Pre-glacial Regions of Wisconsin." *Mid. West Sci.*, Vol. 1, No. 3, pp. 16-20, 1911.

³ Van Hook, O. D. "Effects of Continental Glaciation on Agriculture." *Mid. West Sci.*, Vol. 1, No. 3, pp. 264-1914.

⁴ Lane, J. P., and Gladden, E. W. *Soil Investigation*. Ohio Agr. Exp. Sta., Bul. 564, 1911.

Von Post¹ in a comparison of glacial soils with corresponding residual ones, was able to point out certain general differences. The agricultural condition within the zone of glaciation was always considerably higher than that beyond the regions of drift accumulation. The retention lacking due to glacial erosion and deposition had almost always resulted favorably for agricultural operations. Even the thickness of the drift was found to increase the ground water supply. Not only did this rather conclude that glacial soils were richer in soluble plant-food constituents than residual soils, but he also showed that glacial soils had a greater water-holding power and a higher agricultural value. The abundant textural quality of glacial soils seems adapted to certain staple food crops, and, due to their intermingling, a considerable opportunity for diversified and intermixed farming is offered. It is therefore evident that in any study of soils, particularly those of the United States, a careful consideration of the effects of glaciation is necessary. The great ice sheet has been responsible in more cases for the rejuvenation of our soils, in others for the production of an entirely new soil mantle. Even the abundance in largely dry ice has been not to be ground.

Soil and humus soils.—This distinction between soils due to differences in the formation process is always evident, but is particularly striking in a comparison of soil and humus regions. In cases of light soils the physical aspects are distinct, and decomposition goes on very largely without decomposition. Under humid conditions,

¹ Von Post, O. E. *Glacial Concretions and Reservations*. Bull. Amer. Geog. Soc., Vol. XLV, pp. 359-365. 1914.

² The same complete literature of the subject, see H. Post, O. W. *Soils*, Chapters XX and XXX. New York: 1911.

however, the chemical forces are the determining factor as to the character of the soil. Good soils are therefore usually coarse soils and their color is very likely to be light. Such soils are deep and uniform, there being but little difference between the surface and the subsoil. The needs of the land require accuracy of the texture, particularly in rainfall regions, since the chemical agencies have been so subtle. Various colors may develop because of oxidation, hydration, and the presence of organic matter. Such soils usually are not excessively deep and are likely to be underlain by strata heavier than the surface. The general physical condition and skill of soil soil is uniformly better than that of regions of plentiful rainfall.

Chemically, because of less leaching the soil soils contain more of the important natural plant-food elements. The following analyses bring out the difference in a striking manner:—

| | Iron Range Minnesota | Howe Forest Michigan | Jerome Idaho |
|--------------------------------|---------------------------|-------------------------|---------------------------|
| | Per cent of dry matter | | Per cent of dry matter |
| Available nitrogen and nitrate | | | |
| NH ₄ | 79.97 | 88.31 | 93.36 (100) |
| NH ₄ | 7.51 | 3.06 | 16.81 |
| Protein | 8.40 | 5.96 | 5.58 |
| PO ₄ | .16 | .32 | .39 |
| CaO | 1.43 | .33 | 6.78 |
| MgO | 1.27 | .23 | 3.74 |
| NaCl | .35 | .11 | 3.25 |
| K ₂ O | .67 | .21 | 2.96 |
| Water and sulphur | 5.13 | 6.40 | — |
| Losses | 1.13 | 1.26 | — |

¹ Elzevel, R. W. The Relations of Soil to Climate. U. S. Weather Ser. Bul. 1, 1926.

² Clarke, F. W. Data of Geochemistry. U. S. Geol. Survey, Bul. 601, p. 85, 1911.

It is immediately apparent that the arid soil is poorer in silica than the humid soil, but richer in iron and aluminum, indicating a less weathered condition of the bedrock. Due to a greater amount of leaching, the humid soil is much lower in phosphoric acid, lime, magnesium, sodium, and potassium. The humus in arid soils is somewhat lower than in the soils under better conditions of rainfall, as one would naturally expect. The amount of easily soluble material is higher in arid regions, due to the lack of leaching and the tendency for soluble salts to accumulate. A comparison of the analyses above with Clarke's estimate regarding the composition of the earth shows that the humid-region soil has moved farther away from the average undisturbed rock than the soil produced under conditions of aridity.

Biologically, organisms are found active at greater depths in arid regions than in humid regions, because of the loose structure of arid soils and because of their good aeration. Such soils are seldom water-logged. In humid regions bacterial action is limited very largely to the surface feet of soil, since only there are the aeration and the food conditions adequate. The intensity of biological activity in arid soils is very largely governed by moisture, and when moisture conditions are satisfied bacterial changes may be expected to take place rapidly. Cases are on record in which the soluble salts due to bacterial action have because of arid concentration as to be toxic to plants.

65. Soil color.—Another characteristic of soil is its color, which has originated during the process of soil

¹Urey, C. B. The Distribution and Activities of Elements in Soils of the Arid Region. *Ann. of Calif. Inst. of Geol.*, Vol. 1, No. 2, pp. 1-51. 1916.

formation, largely through natural weathering agencies. This is really a phase of geodesmology, particularly as regards those firms that engender from the oxidation of the iron. Color has long occupied the attention of geologists and agriculturists, in the first place because it gives a clue to the mode of soil formation, and in the second place because it is to a certain extent an index to agricultural value. At the outset it must be understood that soil colors are not pure colors, although spoken of as such, but tints and shades. In soil it is possible to find almost any conceivable color, ranging from white sands to black swamp muds or the blood-red clays of the Piedmont region. The three coloring matters of soil may be classified as (1) the color arising from the mineral, (2) the color given by the humus present in the soil and around the particles, and (3) the color of the yokes due to oxidation of the iron. These three pigments, or bases, colors may be represented for convenience as follows:—



FIG. 5.—A triangular representation of the three primary soil colors and their mixtures.

A soil low in humus, and with the iron either absent or precipitated, will be of a light color. Soils made in good illustrations of this condition. A well-drained soil containing large quantities of organic matter will present a deep black color in spite of the oxidized iron, as the latter will be masked by a large extent. If humus is low or lacking and the iron is oxidized, a red or a yellow color may characterize the soil. As might be expected, there are thousands of these three primary colors, and grays, browns, and yellows of varying intensities are common.

III. White and black soils.—The light colors in soils are not due to the agencies of weathering, but rather to a lack of such action. The cause of such coloration is therefore not hard to explain. The development of the black or dark colors and later, being due to the preservation of organic matter, indicates the operation of two favoring conditions. First, climate agencies that stimulate the luxuriant development of plants; and, secondly, sufficient aeration to promote a favorable decay of such decay. It is a well-recognized fact that in order to develop a black color from decaying vegetable matter, fairly good aeration must be provided. If such a condition does not prevail, the decayed material has a lighter hue and may exhibit toxic properties which will check or inhibit plant growth. The development of the black color, therefore, is a normal well-drained soil, is an indication of good soil sanitation.

III. Red and yellow soils.—The presence of iron, in cherty soils, is a very important factor in soil weathering and the development due to its presence is an infallible indication of chemical decay. The iron in minerals occurs usually as ferrous oxide, which is soluble, especially if the water circulating among the rock fragments carries

carbon dioxide. As this water comes in contact with the air, its excess of carbon dioxide is discharged and the carbon and carbonates of iron are deposited. Under this condition oxidation goes on rapidly, and the iron passes to the ferric state and becomes insoluble. Thus it may be seen that iron imparts a hard surface to roads and pavements in which it may exist, due to its solubility; yet from the oxidation that it undergoes, it tends to permit soil accumulation in soils. A corollary might be added to the law of mineral resistance, to the effect that "the more iron a mineral contains, the more susceptible it is to the weathering agencies."

Therefore, from the geochemical standpoint, the development of the red and yellow colors in soils has been the subject of considerable dispute from time to time. The red and yellow soils of the Cotton States frequently excite comment, especially as a difference in fertility is popularly recognized; the red surface soil with a red subsoil being considered more fertile than a similar soil with a yellow subsoil.¹ Orby² believes that the difference in color is due to a difference in hydration of the iron oxides. The soil temperatures, particularly in tropical and subtropical regions, have first tended to fully oxidize and hydrate the iron, and then to dehydrate the soil at the surface into the deep red color, leaving the subsoil yellow and causing the strata to be markedly oxidized. The ultimate product of both oxidation and hydration would be limonite, a yellow mineral; while if only oxidation were active, hematite, which imparts a red color, would result as a final product. A dehydration of the limonite would cause the formation of hematite

¹ Orby, W. O. Colors of Soils. *Proc. American Nat. Hist. Soc.* 24, pp. 201-202. 1896.

This being true, the thicker the film, the greater is the intensity of the color. The same quantity of iron, therefore, would make a greater showing in a sandy soil than in clay, as the amount of internal surface of the former is comparatively low and the film of iron oxide would therefore be thicker.

It is evident from the data already presented that the intensity of color arising from iron in the soil is due to several conditions. Without a doubt the oxidation that occurs is of primary importance, but the hydration that very often takes place is a powerful modifying agent. The thickness of the film, as determined by the amount of iron present or by the texture of the soil, is probably a factor having to do particularly with the intensity of the coloration, although the color or tint itself may be modified to a certain extent thereby.

4. *Agricultural significance of color.*—The white or the black color of a soil indicates the lack or the presence of an important constituent, namely, organic matter. The weather not only tends to keep the soil in good physical condition, but also acts both as a plant food and as a source of energy for bacteria and other soil organisms. A dark soil, provided its drainage and climatic conditions are favorable, is usually a rich soil. The dark color is no more factor in temperature relationships, since not only does a dark soil absorb heat faster than a light soil, but the tendency of the former toward reflection and radiation is much restricted. This is important with crops which root go into the soil early in the season, or which need to be planted rapidly to maturity. A dark color, with proper and especially, is an excellent guide to fertility and general agricultural value.

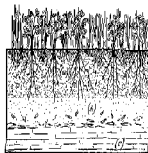
And when is soil often more low or medium regime constant. Besides this, the presence of residual iron is always an indication of age. The residual soils of the Tertiary basins are especially characterized in this way. Age gives opportunities for looking, and consequently a look of the whole basin may be expected in such soils.

The red and the yellow are characteristic of residual soils, or of soils that have arisen from them by erosion or glacialization. A red color is almost as different in the absorption of heat as is black; so that the early growth and quick-maturing tenderness of crops on a red soil, other things being equal, are about the same as on a dark soil. [Haguel]¹ who lays great stress on the agricultural significance of color, considers the mottled yellow and red as indications of poor drainage, since such a mottled shows that oxidation has been both unequal and insufficient. A soil that has a heavy blue or mottled blue clay or a residual soil is most cases is greatly benefited by some form of drainage.

86. Soil and subsoil. A common distinction is made between the surface soil and that which is some distance below the surface. This is natural, as the forces of soil formation have served to bring about certain distinctions, especially in humid regions, which are of importance in any consideration of soil fertility and crop growth. Climatic agencies acting on soil after it has been formed have served to intensify these distinctions. The term soil is used to designate the top layer of earth, which usually extends to the plow line or even deeper. The soil below is known of as the subsoil, and may be rather variable in its depth (Fig. 11). Often the subsoil is divided into the upper

¹ Haguel, *U. S. Soil*, pp. 265-266. New York, 1916.

and the lower subsoil, the upper subsoil being considered to extend to about the depth of three feet below the surface. Usually, especially in humid regions, there is a



The *A*—*B* soil subsoil. (a) Surface soil with many plant roots; (b) subsoil; (c) harder rock.

sharp line of demarcation between the soil and this subsoil, due to differences in the human content. In arid or semiarid countries, where the soil is thin, the soil does not extend to a depth of three feet. Whether the land has been tilled or not, this line of separation is fairly marked and can usually be located with little difficulty. In tilled land, where the surface soil extends to about the depth of plowing, the plow line marks the separation of surface and subsoil. Where soil samples are being taken for soil survey or soil analysis, some arbitrary depth, depending on circumstances, is usually considered for the surface soil. This depth varies from six to twelve inches.

6. *Soil and subsoil of humid regions.* In humid

means there are usually certain well-defined differences between the surface soil and the subsoil, both in the organic content and density of them. The subsoil is usually of a finer soil, less in diameter than the surface soil, due to the downward movement of the small particles. This results in giving the subsoil high water-holding power, and may make it rather impenetrable to water. Poor drainage conditions may result. A certain amount of surface cover is a subsoil is of considerable advantage, in that it aids in the storage of water and prevents the excessive heating away of suitable plant-food. Moreover, almost all the bacterial activities so important in the ripening of manure are kept in the subsoil, being protected by the layer above, but not being subjected to such vigorous over-heating, and as a consequence its action is constantly at work to available for the use of the crop. The deepening of the plow does not a consequent turning-up of the subsoil, and in fact it is very gradually for the above reason. The digging power of a soil may be markedly reduced by the presence of too much of such material on the surface at one time.

The root distribution is restricted largely to the surface soil, and this condition determines to some extent the large accumulation of humus therein and also its better absorption and drainage. Experiments conducted in Utah¹ show that with barley, corn, and clover, from 80 to 95 per cent of the roots grow in the upper seven inches of soil. From experiments made in Kansas² and in North

¹Anderson, J. W. *Roots of Farm Crops*. Utah Agr. Exp. Sta., Bul. 22. 1916.

²The Boyd, A. M. *The Soils of Kansas*. Kansas Agr. Exp. Sta., Bul. 127. 1916.

Dublet's¹ the roots of such crops as alfalfa were found to penetrate to a depth of ten feet, while the small grains often placed an extension of their roots to four feet below the surface. It must be borne in mind, however, that, while some plant roots may penetrate far into the subsoil, the main feeding surface is restricted largely to the surface soil. This is evident, as there they find the oxygen and drainage essential to normal growth. Ellgaard² has shown that plants in arid regions have a root extension far beyond that of the same crops under humid conditions. The physical conditions of the soil subsoil, the larger extent of plowing, and the better aeration, account for such differences.

§2. Soil and subsoil of arid regions. — The animals in arid or semiarid regions do not exhibit such marked contrast to the surface soil as are observed in humid climates. In arid soils there is generally so sharp line of demarcation between soil and subsoil, the latter being so high in humus and in agricultural value as the former. Now is any great natural variation to be observed. The latter condition is due to the fact that physical weathering is dominant in such a region. As a consequence, soil and subsoil may be worked, often economically, in establishing an even surface for the application of irrigation water, without any danger of lowering the fertility thereby. Such a practice in humid regions would be fatal to the further growing of successful crops, at least for a considerable period of years.

¹ Huggins, J. B. *Soil Systems of West China*. N. Y., Mac. Art. Exp. Co., 1914, 64, 1306.

² Ellgaard, E. W. *Soils*, Chapter X, pp. 116-137. New York, 1911.

CHAPTER VI

THE SOIL PARTICLE

The soil formed by the grinding-up of rocks and the dissolving there-with of small quantities of organic matter must be studied physically from the standpoint of its particles. These particles, varying in size from coarse gravel easily discernible by the naked eye to particles so fine as to be invisible under the microscope, determine very largely the different relationships of the soil to the plant. The movement of air in the soil, the circulation of water, the rate of evaporation and hydration, and the presence and vitality of various organisms, are determined very largely by the size of the particles making up the soil. Texture is the term used to express this size of particle. Thus a soil texture may be coarse, medium, or fine, indicating that the particles making up that soil conform in general to such description. Texture is of great importance in soil study and utilization.

There is hardly any condition controlled by the soil that is not influenced, if not directly determined, by the size of the soil particles. A study of plant conditions, whether physical or chemical, ultimately leads either directly or indirectly to a consideration of soil texture. Texture, however, is no element which can be but little modified under normal conditions. We have seen how a rock can be disintegrated and decomposed into a soil. A change in texture has been wrought, but such a process demands geologic ages for its fulfillment. In the time

covered by the life of man the necessary forces are not active enough to have this effect; consequently, as far as the farmer is concerned the texture of the soil is in *fact* subject to but slight alteration. A man treats a soil once a day towards a day, as far as practical considerations are concerned. Changes in texture may be made on a small scale by mixing two soils, but this is not practicable in the field.

63. *Soil separates and mechanical analysis*—The soil particles, varying in size as they do, may be separated into arbitrary divisions, according to their dimensions. The various groups are designated as soil separates, and the process of making the separation and determining the percentage of each group present is called *mechanical analysis*. There are a large number of classifications, or groupings, of the soil particles, as well as several methods of bringing about the actual separation. The grouping and method of mechanical analysis were generally used in this country at that devised by the United States Bureau of Soils.¹ Other methods² are more closely accurate, but speed as well as precision is necessary in this work. A Swedish classification³ of soil particles has been adopted by the Committee on Mechanical Soil Analysis⁴ appointed

¹ Fagn, L. J., and others. *The Official Method of Soil Analysis*. U. S. D. A., Bur. Soils, Bul. 54. 1905.

² For a detailed discussion of all methods of mechanical analysis, see Wiley, C. W. *Agrochemical Analysis*, Vol. 1, pp. 144-251. Boston, Pa. 1904.

³ *Erörtern, A. Die Mechanische Bodenanalyse und die Klassifikation der Mineralischen Bodenbestandteile*. Internat. Mitt. f. Bodenkunde, Band 11, Heft 4, Seite 312-361. 1915.

⁴ *Comité F. Über die Methode der Internationalen Vereinigung für die Mechanische und Physikalische Bodenanalyse*. Verhandl. in Stockholm am 10. October 1913. Internat. Mitt. f. Bodenkunde, Band 17, Heft 1, Seite 1-51. 1914.

by the Second International Agro-Geological Congress, which met in Stockholm in 1931. In simplicity and beauty of interpretation the last-named grouping comes at least equal to that of the theme of Soils. Since a number of methods of mechanical analysis have been devised during the evolution and study of soil separation, it is necessary to be conversant with the principles involved and with at least two or three of the most successful modes of procedure.

64. Principles of mechanical analysis. — The various methods of mechanical analysis may be grouped according to the agents employed in the separation. The outline is as follows:—

Outline of systems of mechanical analysis

1. *Flow* $\left\{ \begin{array}{l} Wet \\ or \\ Dry \end{array} \right.$ (Used inseparably and is practically all methods)
2. *Air* (Archimedes air ebullition)
3. *Water* $\left\{ \begin{array}{l} In vacuo: \left\{ \begin{array}{l} Gravity (Edmond's separator and Hilgard's coarse separator) \\ Centrifugal (Vale's centrifugal separator) \end{array} \right. \\ In mix: \left\{ \begin{array}{l} Gravity (Edmond's beaker method and Hilgard's modified air cylinder) \\ Centrifugal (Hansen of Soils method) \end{array} \right. \end{array} \right.$

In the enumeration of such an outline, certain of the general methods proposed may be eliminated without further paucity since they are inadequate for this separation

in question. Straws of all kinds have the one great (the advantage that their modest cost can be made small enough to separate the finer grades of soil. When one considers that many soil particles are less than 100 microns in diameter, the inadequacy of sieve separation becomes apparent. However, sieves may be used in connection with other methods as an easy way of dealing with the larger soil particles. Air in motion⁴ is inadequate, so it can be used only for very fine particles. Even wind, since the separation is slow and inaccurate because of the tendency of the dry particles to cohere. These two methods have therefore been largely abandoned as the first methods, and water is used as the medium of separation in all the modern systems of mechanical analysis.

The principle involved in the subsidence of soil particles in water, whether the force of gravity or centrifugal force is utilized, is compared by every one. When fragments of rock or soil are suspended in water, they tend to sink slowly, and it is a well-recognized fact that other things being equal, the rate of settling depends on the size of the particle. As the particle is decreased in size, its weight decreases faster than the surface exposed to the buoyant force of the water. As a consequence, the velocity with which the soil particles settle is proportional to their size. The settling of a sample of soil would therefore be the last step in mechanical separation by water; the next step would be subsidence and the withdrawal of each successive grade of particles as it slowly settled; the third step would be determination of the percentage of each grade, or grade, of particles.

⁴Chakman, A. R., and Paulsen, P. *The Principles of Soil Testing*. Jour. Res. Coun. Agr., VA. 20, No. 4, pp. 469-497, 1937.

is based on the original sample. This is precisely what every method of mechanical analysis in which water is utilized aims to do, although often the apparatus and technique are excessively complicated.

10. Mechanical analysis by water is simple. Stobbe's separator — long glass tube that is designed to separate particles of different sizes by water in motion, may be designated as an electric separator. One of these, commonly used in Europe, is called Stobbe's separator.

This utilizes hydraulic force. In it the upward current of water causes a central glass tube (see Fig. 11) from a narrow central inlet tube below. The soil sample present in the inlet tube is kept agitated by the current. It is noted that by regulating the rate of flow of the water, different sizes of particles will be carried away over the top of the central glass tube. Thus by a gentle flow only fine grades will be separated, while by increasing the current larger and still larger particles will be carried upward against the force of gravity.

These are three objections to this method. First, the entrance tube may become clogged and, unless a very small



FIG. 11. Stobbe's separator for mechanical analysis with water as medium.

¹Stobbe, H. (1886) *Zeitschrift für Analytische Chemie*, 11, 281. Separators for Mechanical Analysis, 8, 7, p. 1, p. 128, 1882. Über die Mechanik der Wasserbewegung und die neue Methode der mechanischen Analyse, 8, 7, p. 1, p. 128, 1882. Über die Mechanik der Wasserbewegung und die neue Methode der mechanischen Analyse, 8, 7, p. 1, p. 128, 1882. Separators, 8, 7, p. 1, p. 128, 1882.

quantity of soil is used, the mass is not kept properly agitated; secondly, coarse currents are set up in the central glass tube, which vitiates the results; and, thirdly, the separate particles tend to resolve into granules. It is evident that in any separation of soil particles all granulation must be avoided. This is easily accomplished by shaking or boiling the sample previous to the determination. The tendency toward granulation during the process of separation tends to lead to inaccuracy, as coarser particles carrying a large number of small grains would fail to pass over at water-current velocities corresponding to their component parts.

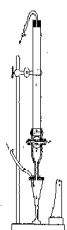


FIG. 11.—Hilgard's elutriator for separating soil masses of particles of small size. (a) sample; (b) water; (c) water; (d) water; (e) water; (f) water; (g) water; (h) water; (i) water; (j) water; (k) water; (l) water; (m) water; (n) water; (o) water; (p) water; (q) water; (r) water; (s) water; (t) water; (u) water; (v) water; (w) water; (x) water; (y) water; (z) water.

Hilgard, E. W. Methods of Physical and Chemical Soil Analysis. Am. Soc. California Agr. Exp. Sta., pp. 241-242, 1891, 1892.

formation of suspended particles. A screen placed just above the stream serves to prevent the whirling motion from being communicated to the ascending column of water in which the separation occurs. The various grades in the separation are regulated by the rate of water flow. With this apparatus it is necessary to remove the fine particles before 30 min. in order to avoid any subsideance previous to the determination.

While this method is very easily accurate and will give separation of the various grades without is impossible with most other methods, it is impracticable in ordinary mill work. The large quantity of water which is used in carrying over each grade, and which of course must be evaporated before the sample can be weighed, is the first objection. The length of time necessary for the separation, and the cost of the apparatus are two well-defined objections well known to it. An extended analysis is next largely in determining and texture, rigidity and ease of separation are of more importance than the extremely accurate separation of the particles.

55. Yaker's centrifugal separator. - One of the objections to the methods already described is the length of time necessary for a determination. This is due to the fact that very fine particles subside in water very slowly. In order to hasten the separation, Yaker¹ devised a machine in which hydraulic force may be supplemented by a centrifugal pull. This ingenious apparatus consists of an elliptical bottle (see Fig. 15) mounted in a centrifuge. The muddy water is introduced into the bottle at the center of the centrifuge. It then passes to the bottom of the bottle and back again to the

¹Yaker, *U. S. A. Rev. Centrifugal and Hydraulic. Wash. Rep. Res. Bul.*, Vol. 86, 1904.

surface, varying with it a sediment the size of which depends on the rate of water flow and the strength of the centrifugal force. The bottle is so designed that particles in all parts of the separating chamber are subjected to the same force, no matter what their distance



FIG. 11.—Laboratory bottle for centrifugal separation. (Cf. Note: a), bottle; b), to be the maximum limit in bottom of separating bottle; c), at 60°; d), centrifugal; e), centrifugal; f), centrifugal.

from the center of the centrifuge may be. The apparatus may be used only for separating particles less than 20 millimeter in diameter. It is open to the same objections that apply to Elgert's machine, besides being very much more complicated and delicately adjusted. It is decidedly an apparatus for ordinary work.

6. Mechanical analysis by water at rest. Osborn's basket method.—One of the earliest and most nearly accurate methods to be perfected was the separation of the various grades of soil by suspension in a column of still water. This is commonly spoken of as the Osborn basket method.¹ The determination is very simple. The soil sample is first fully deflocculated and stirred into suspension, each particle determining separately. Baskets are commonly used as containers, but

¹ Osborn, T. B. *Methods of Mechanical Soil Analysis*. Eng. Exp. Stations, 1884, pp. 211-226; 1887, pp. 244-250; 1898, pp. 154-155.

any vessel that is relatively deep will do for the decantation. The larger particles, or seed grains, will of course settle first, and the finer silts and clays may be decanted off. As the water carries fine particles down with them, the suspension and subsidence must be repeated a number of times. The finer particles, repeated thus and decanted, may be further subdivided in the same manner. The time necessary for such decantation as will leave in suspension only particles below a given size is determined by the coarseness of a drop of the suspension under a microscope fitted with an eyepiece micrometer. In this way the size of the particles decanted may be accurately measured.

The three steps in this method of separation are: differentiation of the sample, separation by successive subsidence and decantation; and separation by dryness of the separates and their calculation to a percentage based on the original sample. The method, however, is slow, as the time necessary for each subsidence of the finer particles is very great and the number of individual subsidences is large. Neither is the method capable of the refinement of separation which is possible with certain of the detectors. As a consequence it has been superseded by methods that utilize centrifugal force for the finer separations while retaining gravity for removing the heavier grades of sand.

6. Atterberg's modified *Aggral*¹ silt cylinder (Fig. 14).—This method² is similar to the Becker method in

¹Aggral, G. Untersuchungen über den Aufbau der Böden und Wässerungen. Bericht an d. Kaiserl. d. Aggr.-Physik. Band II, Seite 295-307, 1904.

²Atterberg, A. Ein Mechanisches Trennverfahren und die Klassifikation der Mineralischen Böden. Internat. Zeit. f. Bodenkunde, Band II, Heft 4, Seite 315-342, 1915.

general principle, but a special apparatus is employed by means of which the various grades obtained by sedimentation are separated off instead of discarded. The cylinder is really a modified "Wilmshurst cylinder" such as was used in early soil analyses for clearing off the various suspensions except the silt which is placed outside the cylinder instead of inside.



FIG. 14.—Atterberg's glass cylinder for the sedimentation analysis of soil suspensions.

The cylinder (de Schloemann) as used by Atterberg is about 55 centimeters high, with a glass pedestal and a ground glass stopper. It is graduated at 5, 10, 15, and 20 centimeters upward from the bottom. The water distance is divided also into 10 divisions at the left of the first graduation. The latter graduation is used in the separation of the clay (Schlamm), so that the height of the sedimenting column may be regulated according to the time available for the settling process. An outside scale, 4 to 5 millimeters wide is attached to the cylinder at the bottom for the knowing of the liquid when the sedimentation is complete. The top of this cylinder is opposite the 5-centimeter mark on the cylinder. Cylinders

of this size are used only for the separation of particles below 2 millimeter in diameter; for larger particles a somewhat taller cylinder is used, with a siphon at the

¹ Wiley, H. W. *Agrochemical Analysis*, pp. 202-207. New York, 1900.

same width as for the finer particles. The graduation of the cylinder and its diameter are the same as described above.

A 50-gram sample of soil is used with this separator, and defeculation is brought about by means of a still larger. The sample is reduced to a paste in a porcelain dish, and then, by alternate working with the brush and decanting, all the particles are thrown into separate suspensions. A defeculating chemical is used in heavy soils, in order to hasten the process and counteract the effect of the organic matter. As in the beaker method, the size of the various grades of separation may be varied according to the will of the operator.

25. *Centrifugal and analysis.*—Of the centrifugal methods used in mechanical analysis, that employed by the United States Bureau of Soils¹ is the most successful.

A 50-gram sample of well-pulverized soil is put into a shaker bottle of about 350 cubic centimeters capacity (see Fig. 15). This bottle is filled about two-thirds full of water, so that in shaking the distinguishing force of the liquid may be utilized. A few drops of ammonia are added, to dissolve the organic matter and to make defeculation easier. The sample is then agitated in the bottle until disintegration is complete. The period ranges from five to twenty hours, depending on the sample.

The separation of the silt and the clay from the sands is made in the shaker bottle by simple subsidence, the fine fraction remaining being discarded by a subsequent examination of a drop of the suspension. The silt and

¹Wheeler, H. C., and Bryan, E. *Modifications of the Method of Soil Analysis*. U. S. D. A., Bur. Soils, Bul. 36, 1915.

the clay are decanted directly into a test tube fitted into a centrifuge (see Fig. 15). Whirling at the rate of 800 to 1000 revolutions a minute will cause the sedimentation of the silt to the bottom of the test tube in a few minutes. The clay is then decanted. The microscope is necessary here, in order to determine when the settling of the silt is complete. As small particles tend to cling to the larger particles, the entire operation must be repeated

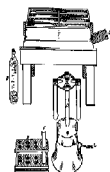


Fig. 15—Apparatus for centrifugal mechanical analysis of soil, sludge, fine clastic rocks, shales, sandstones, and limestones.

several times; therefore the presence of gravity sediments and centrifugal sedimentation are avoided on side by side, material being constantly passed from the shaker bottle into the centrifuge tubes and from the test tubes into the receptacles for the clay.

The centrifuge is usually large enough to allow the separation of several duplicate samples at once. The various separations made by this method are direct and

weighed. The sands, which are obtained in bulk, are further separated by sieves into the grades desired. When a large quantity of organic matter is present, it must be determined and included in the final report on the sample.

The method of mechanical analysis as perfected by the Bureau of Soils has been very generally adopted by soil workers. It has many advantages over other methods. In the first place, it is rapid, often requiring only hours when other methods take days for completion; secondly, it is simple, and the technique of the separation is easily acquired; thirdly, in the determination of very large amounts of water in unconsolidated soils the apparatus, except for the clay, and also the time and cost of comparison is diminished. The clay, moreover, may be as accurately determined by difference as by direct methods, thus allowing a further saving of time. The cost of the equipment for this method is low. The apparatus itself is simple, and is carried by all standard chemical companies. The same cannot be said of the various electrical mechanisms. While the method is accurate only within one per cent, it is sufficiently precise for practical purposes, especially in clay determination, for which mechanical analysis is generally utilized.

(3) *Classification of soil particles*.—With the large number of different methods of mechanical soil analysis there has arisen a large variation in actual groupings expressed in diameter of particles. This would naturally occur because of the difference in degree of refinement with the various methods of separation alone, and also because of the ease with which the boundaries varied in size of such analyses. Some of the best-known groupings are given below:

TABLE VI
Various Technical Characterizations of the Various
and Average of Data: Estimates of Character of
Processes in Millstones

| Reactor | Quartz ¹ | Fluorite ² | Barite ³ Recryst. | Fluorite ⁴ | Quartz ⁵ |
|---------|---------------------|-----------------------|---------------------------------|-----------------------|---------------------|
| 1 | 3.00 | 3.00 | 3.00 | 1.00 | 25.00 |
| 2 | 1.00 | 1.00 | 1.00 | .20 | 5.00 |
| 3 | .50 | .50 | .50 | .05 | .50 |
| 4 | .50 | .50 | .50 | .05 | .50 |
| 5 | .50 | .50 | .50 | .05 | .50 |
| 6 | .50 | .50 | .50 | .05 | .50 |
| 7 | .50 | .50 | .50 | .05 | .50 |
| 8 | .50 | .50 | .50 | .05 | .50 |
| 9 | .50 | .50 | .50 | .05 | .50 |
| 10 | .50 | .50 | .50 | .05 | .50 |
| 11 | .50 | .50 | .50 | .05 | .50 |
| 12 | .50 | .50 | .50 | .05 | .50 |

(If these characterizations only three and claim our attention—that of the Bureau of Soils, that of Hill and Russell (the Wright characterizations), and that derived by Atterberg. These represent the groupings used in its present classification and analysis in the United States.

¹Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920, pp. 141-148; 1921, pp. 141-148; 1922, pp. 141-148.

²Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

³Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

⁴Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

⁵Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

⁶Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

⁷Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

⁸Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

⁹Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

¹⁰Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

¹¹Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

¹²Johnson, T. B. *Methods of Mechanical Soil Analysis*. Ann. Rept. Connecticut Agr. Exp. Sta., 1920-1921, pp. 141-148.

is English, and is Continental Europe, respectively, as to which is the best for an interpretation and comparison of textual qualities it is difficult to say. They are all arbitrary, yet they are all extremely useful. It therefore seems immaterial which one is employed. It would be better, of course, if the classifications were uniform for all countries; modification of mill properties would thereby ensue.

II. *Source of fibre classification.*—As the grouping established by the United States Bureau of Soils is not such in all of our mill literature, and as it is really the *standard* classification for the country, a close consideration of it may be profitable. The discussion of the properties exhibited by the various species, and of the interpretation and value of a mechanical analysis, will therefore be made with this classification as a basis. By way of illustrating the grouping and the mode of comparing a mechanical analysis the results obtained from two distinctly different soils are given below:—

MEMBERSHIP ANALYSIS¹ OF A PRUNUS FRUIT-SKIN FIBRE AND A LIGNINE SLAT.

| Members | Size in Microns | Per Cent | Class |
|-------------------------|-----------------|----------|-------|
| | | 8 | 8 |
| Very good | 2-4 | 1 | 1 |
| Good med | 4-5 | 2 | 2 |
| Medium med | 5-15 | 3 | 3 |
| Poor med | 15-30 | 22 | 4 |
| Very poor med | 35-65 | 28 | 5 |
| Slit | 65-100 | 27 | 20 |
| Clay | above 100 | 11 | 12 |

¹ *Textile Storage Field Book*, pp. 159, 164. F. R. T. A., Ser. 1020.

75. *Physical character of the aggregates*.—It is immediately apparent that no three groups vary in size they must exhibit properties, especially physical ones, which are widely different. These properties should in turn be imparted to the soil of which the aggregates form a part. If no one movement with these various values, a mechanical analysis should reveal to us at a glance certain soil conditions which may or may not be conducive to the best plant growth.

The clay particles are very minute; many of them are so small as to be invisible under the ultramicroscope. They are easily sheared and fragments of minerals, and are jagged and angular in outline. They are highly plastic; and when rubbed together they become sticky and impervious. They shrink much on drying, with the exception of considerable lumps. On being wet again they swell with the evolution of the heat already taken up. Many of the particles exhibit the Brownian movement and will remain in suspension for an indefinite period. The finer part of the clay makes up a portion of that indistinct group of material in the soil called colloids, which because of their freedom of motion (colloidal complexes) exhibit certain well-defined properties, of which absorption of moisture and salts in solution, and high plasticity and cohesion, are the most important from a soil standpoint. Silica exhibits the same qualities as clay, but to a much less marked extent. The presence of clay in a soil imparts to it a heavy texture, with a tendency to draw water and air downwards. Such a soil is highly plastic, but becomes sticky when too wet and hard and cloddy when too dry. The expansion and the contraction on wetting and drying are very great. The waterholding capacity of a clay soil is high.

The spherule and the gravel, because of their size, have no separate particles. They are integral and monolithic, the natural feeling that they have retained being sufficient to lose almost their angular character. They exhibit very low plasticity and cohesion, and as a consequence little influenced by changes in water content. Their waterholding capacity is low, and because of the large size of the spaces between such separate particles the passage of water is rapid. They therefore facilitate drainage and encourage good air movement. In all the grades of sand the separate particles are visible to the naked eye, a condition impossible with the silt and clay groups. Soil containing much sand or gravel, therefore, is of an open character, possessing good drainage and aeration, and is usually in a loose friable condition.

14. Microscopical characteristics of the separate.—From the microscopical standpoint there are usually considerable differences in the soil separates. These differences would naturally be expected to occur particularly in *mineral soils*, because of the differentiating tendencies of weathering. Quartz would naturally persist, and because of its slow solubility would very soon make up most of the larger soil grains. Other minerals, such as the feldspars, hornblende, augite, and the like, being less persistent in the face of natural conditions has already caught us, would be worn to the shreds and be found as the main constituents of the silty and the clays. The following data contain this description regarding the microscopical characteristics of some of the soil groups as designated by the Bureau of Soils as well as furnish some interesting comparisons of more important soil provinces:

CHEMICAL MINERALIZATION: COMPARISON OF THE RANGE AND
RANGE OF FERTILIZER VALUES OF THE VARIOUS SOILS

| Soil | No. of factors | MINERALIZATION VALUE Quartz or | |
|-------------------------|-------------------|-----------------------------------|-------|
| | | Soils | Slits |
| Topsoil | 12 | 15% | 20% |
| Clay and loam | 0 | 25% | 10% |
| Humus | 4 | 5% | 0% |
| AND | 2 | 27% | 40% |

It is to be seen immediately that in every case the soil carries a larger quantity of the important soil-forming minerals and a smaller quantity of quartz than does the sand. This results at least one of the reasons for the greater fertility and lasting qualities of low-ventral soils as far as agricultural operations are concerned. It is important to note, however, that, although quartz is the predominant mineral in soils, all the common soil-forming minerals are usually necessary. This activity serves to again emphasize the fact that all soils contain all the common minerals found in soil-forming rocks.

It is also interesting to note the general differences exhibited by the various soil profiles. The volcanic, glacial, and coastal plain soils possess minerals other than quartz in the other states. In the marine soils, in particular, this difference has largely come about by the disintegration and leaching that these soils have undergone during their formation. The acid soils, due to the suppression of chemical weathering and the activity

* McLaughlin, F. C., and Wilson, R. P. The Mineralogy of Soil-Forming Minerals. U. S. G. A., *Bull.* of Geol., Vol. 90, 1912.

of the physical agents, exhibit smaller quantities of fine quartz. The silica in such soils is held so complex and dense, which very largely carry the elements that are so important in plant development.

Although these data are based on but a few samples, they are so consistent with what would naturally be expected that the general conclusions cannot be avoided.

%. The chemical constitution of soil particles.—The mineralogical examination of soils has revealed a larger percentage of such minerals as feldspars, mica, hornblende, and the like, in the finer sequences. A larger percentage of the important glass-like elements would therefore be expected in these groups. The following data, compiled here, were prepared by the United States Bureau of Soils, substantiate this assumption:—

Chemical Constitution of Various Soil Sequences

| Soil | No. of samples | Percentage of Silica in Soil | | | Percentage of Silica in Clay | | |
|---------------------|----------------|------------------------------|-----|--------------------------------|------------------------------|-----|--------------------------------|
| | | SiO ₂ | FeO | Al ₂ O ₃ | SiO ₂ | FeO | Al ₂ O ₃ |
| Quaternary residual | 1 | 57 | 25 | 18 | 52 | 28 | 20 |
| Quaternary residual | 2 | 59 | 25 | 17 | 51 | 29 | 20 |
| Quaternary residual | 3 | 61 | 25 | 16 | 52 | 28 | 20 |
| Quaternary residual | 4 | 61 | 25 | 16 | 52 | 28 | 20 |
| Quaternary residual | 5 | 61 | 25 | 16 | 52 | 28 | 20 |

It is seen that on the average the soils with finer particles are richer in phosphoric acid, potash, and lime, than those of coarser texture, the only exception to this rule being in the case of the residual horizon soils. The soils with present a less marked difference in the results.

¹ Holmes, G. H., and others. The Mineral Constitution of Soil Particles. U. S. D. A., Bur. Soils, Bul. 64, 1908.

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sals, and also than the representation of the other soil portions; this is true also of the glacial soils, but to a less degree. Under such conditions of weathering the soils have not as yet been depleted of their stores of essential elements. Average data compiled from a number of soil analyses by Hall¹ presented below, tend to corroborate the data already noted and that obtained by Longbridge² of California:

COMPARISON OF SOIL RESOURCES

| | Feet | 1000 | 1000 | 1000 | 1000 | 1000 |
|-----------------------|------|------|------|------|------|------|
| | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| Overland (1-2 mm.) | 10.0 | 1.6 | 1.2 | 4 | 5 | 8.06 |
| Plowland (2-20 mm.) | 84.0 | 2.0 | 1.2 | 5 | 8 | 1.2 |
| Sub (20-100 mm.) | 88.1 | 1.1 | 1.5 | 8 | 1 | 2.3 |
| Forest (100-1000 mm.) | 76.2 | 1.2 | 1.1 | 1.8 | 3 | 1.2 |
| Clay (1000-10000 mm.) | 10.2 | 10.2 | 10.2 | 1.5 | 1.1 | 1.9 |

M. Value of a mechanical analysis.—It is very evident that the proper interpretation of a mechanical analysis throws considerable light on the probable physical and chemical properties of a soil. To the limited observer the preponderance of sand in clay implies certain physical properties which may affect the plant not only mechanically, but physiologically as well, through varia-

¹Hall, A. H., and Howell, H. J. Soil Strength and Soil Analysis. Jour. Agr. Science, Vol. IV, Part 2, p. 190, 1913.

Also a Report of the Agriculture and State of Idaho, Idaho, and Idaho. Board of Agriculture and Forestry, 1911.

²Longbridge, M. H. On the Distribution of Soil Impurities among Substrata Observed in 1911. Analyt. Anst. Jour. Sci. Res. VI, p. 27, 1912.

In this connection see also Schubert, Dr. Über die Veränderung von Nährstoffen in den Vegetationsstadien der Böden. Zeitschr. für Geol., Band 10, Seite 190-210, 1907.

flow in air and water movements. The chemical phases of soil as interpretations are also worthy of consideration, as the properties of the various separate determinations whether the essential plant-food elements will be present in sufficient quantities to permit normal crop growth. Thus is a general way the mechanical analysis of a soil not only enlightens us as to the general properties of a given soil, but it is to some extent a criterion of agricultural value and crop adaptation. Some authors¹ maintain that in the investigation of any soil a mechanical analysis should first be made, so such an analysis throws so much light on the general qualities of a soil.

11. *Soil class*.—*Class* is a term used in relation to the texture, or size of particles, of a soil. *Class* differs from texture, however, in that it has reference rather to the particular properties exhibited by a soil than to any absolute grain size. As with one set made up of particles of the same size, a basket full of marbles which will not only give an idea of the texture of the soil, but also cause it to react in a manner as to several general possibilities and properties. We may have any number of classes, depending on the sizes of the soil grains mixed.

These class names have originated through long centuries of agricultural operations, but of late they have been more or less standardized because of the necessity of a definite nomenclature. In general the names used for the soil classes are the same as are used in mechanical analyses to designate the soil separation. This is rather unfortunate, but it obviates the necessity of technical terms with a little care will present confusion in this regard.

Another word introduced by common usage is *loam*.

¹ Hall, G. D., and Gifford, H. F. Soil Groups and Soil Analysis. Amer. Agr. Science, Vol. 27, Part 2, p. 120. 1911.

Loca, from the technical standpoint, refers to a soil preventing it about equal amounts the properties reported by the various equations. If, however, we have practically the same condition but with one fixed factor predominating the name of that particular agent is preferred, giving still more data regarding the soil in question. Thus a loam in which clay is dominant will be classified as a clay loam. In the same way we may have a sandy loam, a sandy clay loam, a gravelly sandy clayey loam, and so on. The number of soil classes that may occur is therefore rather large, ranging from coarse gravel, through the various grades of sands, to silts and clays.

A few of the common classes, with their mechanical analyses, are listed below:—

MECHANICAL COMPOSITION OF VARIOUS SOIL CLASSES¹

| | Gravel No. 20 or larger | Sand No. 60 or larger | Silt No. 20 to 60 | Clay No. 200 or larger | Water | Loss on drying |
|----------------------------|----------------------------------|--------------------------------|----------------------------|---------------------------------|-------|----------------------|
| Coarse sands | 335 | 12 | 37 | 18 | 0 | 7 |
| Medium | 400 | 2 | 10 | 25 | 15 | 7 |
| Fine sands | 511 | 1 | 4 | 30 | 17 | 4 |
| Sandy loams | 514 | 6 | 13 | 32 | 15 | 13 |
| Fine sandy loams | 638 | 1 | 3 | 1 | 55 | 12 |
| Loams | 639 | 2 | 5 | 12 | 57 | 10 |
| Silty loams | 659 | 1 | 2 | 1 | 11 | 10 |
| Sandy clays | 952 | 2 | 8 | 1 | 98 | 15 |
| Clay loams | 712 | 1 | 4 | 1 | 14 | 15 |
| Silty clay loams | 712 | 0 | 2 | 1 | 7 | 15 |
| Clays | 873 | 1 | 1 | 2 | 9 | 14 |

¹ Whitney, M. "The Use of Soil Tests of the Great Plains." U. S. D. A. Bur. Soils, Bul. No. 3, 12, 1911.

is evident that a mechanical analysis of a soil is adding more or less than an expression of them, and the inference that may be derived from either one or the other, this leads to a consideration of their determinative.

18. *Determination of class*.—The common method of class determination is that employed in the field. It consists in examination of the soil as to color, an estimation of its loam content, and, especially, a testing of the "feel" of the soil. Probably as much can be judged as to the texture and class of a soil by merely rubbing it between the thumb and the fingers as by any other empirical method. This is a method used in all field operations, especially in soil survey work. The accuracy of the determination depends largely on experience. Inconsistencies are likely to occur in distinguishing between the various four grades of soil, for the reason more weakly exact methods are necessary at times, especially in checking soil survey work or in carrying out investigation in which absolute accuracy is required.

As a mechanical analysis of a soil is really a percentage expression of texture, it presents an exact method for class determination. For detailed work somewhat complicated tables¹ have been arranged, but the following diagram (Fig. 1), devised by Whitney,² presents a simple method for the classification of a soil from a mechanical analysis. The convenience of this triangular representation may be tested by the use of the average analyses, already presented on a previous page.

¹ *Rep. of Soil, Soil Survey Field Book*, p. 17, U. S. D. A., Agr. Bk., 1905. Also, *Soil Bk.*, vol. 76, p. 13, 1914.

² Whitney, W. The Use of Soil Tests of the Great Plains.

Agrochim., R. S. D. A., *Proc. Bk.*, vol. 26, p. 95, 1911.

THE MECHANICAL ANALYSIS OF FERTILIZER GRAIN SUGAR

| | Water (% moisture) | Alkali (% moisture) | Phosphorus (% moisture) | Iron (% moisture) | Other (% moisture) |
|------------|-----------------------|------------------------|----------------------------|----------------------|-----------------------|
| Phosphorus | 14 | 15 | 5 | 12 | 11 |
| Chlorine | 37 | 185 | 20.1 | 68 | 84 |
| Sulfur | 24.5 | 22.5 | 65.5 | 20.5 | 22.5 |
| Iron | 20.5 | 15.5 | 25.5 | 70.5 | 20.5 |
| Phosphorus | 12.5 | 8.5 | 8.5 | 3.5 | 7.5 |
| Chlorine | 20.5 | 11.5 | 8.5 | 12.5 | 11.5 |

The soil particle can then be seen to function in no important manner regarding plant nutrition. Its size, its physical characteristics, its chemical composition, and the conditions imposed by a preponderance or a limitation in the various grades, are of vital importance. Soil texture and soil time, therefore, are factors of constant value in soil discussion and study, whether the viewpoint is practical or purely theoretical.

CHAPTER VII

SOME PHYSICAL PROPERTIES OF THE SOIL

While texture is of great importance in the determination of the physical and chemical nature of a soil, it is evident that the arrangement of the particles also exerts considerable influence. The term texture refers to the size of the soil particles; the term structure is used in reference to their arrangement, or grouping. It is at once apparent that certain conditions—such, for example, as air and water movement, heat transfer, etc., and the like—will be as much affected by structure as by texture. As a matter of fact, the great changes wrought by the farmer in making his soil better suited as a fieldbed for plants are structural changes rather than changes in texture. The compacting of a light soil or the loosening of a heavy soil is merely a change in arrangement of the soil grains. It is of interest, therefore, to ascertain the probable arrangement of the particles in any soil.

80. Arrangement of soil particles (Fig. 17). In my consideration it is the easier way to advance from the simple to the complex. Therefore in the explanation of structural relationships a theoretical condition will be dealt with first, after which the discussion will proceed to the intricate condition existing in the soil. Assuming that this theoretical condition consists in spherical particles all of the same size, we find three particles susceptible

in two different arrangements: (1) in adjacent order, with each particle touching in four points by its neighbors; and (2) the oblique, in which each particle is in contact with six of its neighbors. The possible pore space in the first case is 47.64 per cent, while that in the second case is 28.36 per cent. The amount of this pore space is undiminished by the size of the particles, provided they are round and all of the same volume.

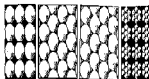


FIG. 11.—Four arrangements of spherical particles, showing how soil particles, spheres, cubes, and irregular solids.

To say one of practical experience is it is well-known fact that the soil particles are not homogeneous as to size, and neither do all the particles function as single grains, being gathered together in groups called granules, or crumbs. A small particle of soil may be made up of a number of very small grains. This will modify the ideal condition as described above, giving two additional conditions—first, a mixture of spherical grains of different sizes, and, secondly, a condition in which the large grains are composed made up of numerous small particles. A mixture such as is produced by the first of these conditions, in which the small grains fit in between the larger ones, will result in a reduction of pore space. The pore space will fall below 48.36 per cent and approach zero. A real soil having such restricted pore space is

designed to bring in a partial condition. This condition is restricted to plant growth, for it not only impedes not development and extension, but also prevents the circulation of air and water, a function necessary for proper soil aeration. In the second condition an increase in pore space must occur, as each large grain presents considerable internal air space. If the granules as well as their component particles were arranged in optimum order, the pore space would reach the high percentage of 75.18. Under natural conditions, then, the pore space might range from zero plus to about 75 per cent.

However, not only are the particles of a natural soil not of the same size, but they are far from round. A soil is already disintegrated, originally presents varying amounts of particles, ranging in size from stone and coarse gravel to the very finest clay. These particles may also differ in shape, varying from almost perfect spheres to flakes, plates, and fragments of every conceivable form. Therefore the laws that apply to the ideal condition will hold only in a general way in a natural soil. It is evident, first, that the more compact the soil, the less is the pore space; secondly, that it is possible to so manipulate a soil as to work the small particles in between the larger ones and create an impervious or puddled condition; and, thirdly, that by the forming of granules the pore space of a soil may be increased to a high percentage.

From the standpoint of size and arrangement of particles there are really two classes of soils, those of single grain structure and those that are granular. In the former each particle functions separately. In order to do this the particles must be large. This condition is found in

and. In such soil would naturally be found also a voidness to low pore space, just as has been exemplified in the ideal condition described above. In granular soils, the granules, being made up of small particles, present much internal pore space. This condition occurs only in fine soils, such as loams, silts, and clays, since large particles will not cohere firmly enough to produce a *crumb* structure. A fine textured soil, which will puddle more readily than a coarse one, is thus moved from a semi-superficial condition by the tendency toward granulation.

The ideal soil condition might be considered to be most likely to occur in a loam (Fig. 3). In loamy soil some of the particles are large, and function separately; others are medium in size and tend to form the nuclei around which smaller particles may cluster to form granules, or crumbs. There are then a few large pore spaces which facilitate drainage, and numerous small openings in which water is retained. Air circulation is easy increased, and saturation is prevented. In such a condition the capillary water plays an important part. This condition is, of course, particularly desirable for the growth of the grain and lighter the soil, and constitutes much in keeping about the heavy condition so favorable to plant development. Because of its water-holding capacity also it proves a valuable addition. Then with



FIG. 3. The average condition of a loam soil and of good structural condition. (a) large crumb; (b) small crumb; (c) large pore space; (d) small pore space; (e) large pore space.

particles of varying sizes, of a structure partly spherulitic and partly granular, to which has been added by natural means sufficient organic matter in an advanced stage of decomposition, we have the ideal soil conditions for plant development. Yet the same has grown here in a general way as seen fitted to function with human purposes grains of spherical shape.

31. *The absolute specific gravity of the soil* — The structural condition of any soil, be it spherulitic, granular, or a favorable combination of the two, has considerable influence on certain other physical conditions. One of these most affected is the weight. The weight of a soil is determined by two factors — the weight of the individual particles, or the absolute specific gravity; and the amount of water space taken up by each particle in any given volume. The latter is really a structural condition and is independent to some extent of the size of particles. The absolute specific gravity, or weight, compared with an equal volume of water, of some of the common minerals is as follows:

| | | | |
|----------------------|------|----------------------|-----|
| Quartz | 2.65 | Apatite | 3.1 |
| Olivine | 3.3 | Oxymal | 3.5 |
| Thapsidite | 3.7 | Monazite | 5.2 |
| Mica | 2.8 | Limonite | 4.0 |
| Illite | 2.6 | Serpentine | 2.6 |
| Calcite | 2.7 | Chlorite | 2.2 |
| Dolomite | 2.9 | Talc | 2.7 |

Although a great range is observed in the absolute specific gravities of these common soil-forming minerals, it must be remembered that such minerals as quartz and talc are usually under the bulk of a soil. As a consequence it has been found that the absolute specific

gravity of a purely mineral soil varies only between narrow limits, there being from 2.6 to 2.8. *Nor* has fluxes any appreciable effect, as shown below by Wilby's¹ determinations on the various separates:—

| SPECIFIC GRAVITY | |
|--------------------------------------|------|
| Very coarse (2-4 mm.) | 2.67 |
| Coarse sand (1-5 mm.) | 2.65 |
| Medium sand (5-25 mm.) | 2.68 |
| Fine sand (25-50 mm.) | 2.69 |
| Very fine sand (10-16 mm.) | 2.69 |
| Silt (16-300 mm.) | 2.68 |
| Clay (below 100 mm.) | 2.87 |

The only marked variation here observed is in the clay separate, and this may be due to the concentration of the iron-bearing silicates in this grade. However, for all practical purposes the average absolute specific gravity of a mineral soil may be placed at about 2.70. One condition that may vary this is the quantity of organic matter present. As the specific gravity of the soil varies usually ranges from 1.2 to 1.7, the more humus there is present, the lower will be the absolute figure for a given soil. A purely organic soil, such as peat or *peat*, presents a variable absolute specific gravity ranging from 1.4 to 1.6, according to the amount of water it has absorbed from mineral sources. Some humus-rich soils may drop as low as 1.1. Nevertheless for general calculations the average mineral soil may be considered to have an absolute specific gravity of about 2.70.

82. *Apparent specific gravity.*—Here all soils contain water or fine pore spaces, depending on texture and structure.

¹Wilby, M. Some Physical Properties of Soils. U. S. D. A., Bulletin No. 161, p. 25, 1902.

tural conditions, the actual weight of the absolutely dry soil in any volume is of great importance. This is expressed as the absolute specific gravity of any material, the weight of an equal volume of water being used as a unit. Because of their tendency to granulate, fine soils have a very large coefficient of porosity, as has been shown in the discussion of structure; it is to be expected, therefore, that they will weigh less in any particular volume than will soils made up of large particles. Coarse soils are heavy soils, as far as weight is concerned. Mineral soils may range in apparent specific gravity¹ from 1.30 to 1.80 for clay to 1.35 to 1.55 for sand. Humus lumps may drop as low as 1.60, and much often reaches the low figure of .80. The apparent specific gravity is always expressed on the basis of absolutely dry soil.



FIG. 10.—Cylinder for determining the apparent specific gravity of soil in the field. The volume ratio of (C) to (A) is known, and in accordance to weight measure (which is known for that of the cylinder and the weight of water) gives the apparent specific

gravity of soil. The apparent specific gravity of soil may be determined by filling a cylinder of known volume with the soil, and obtaining thereby a unit of material and (see Fig. 10).

In the field the apparent specific gravity of a soil may be determined by filling a cylinder of known volume with the soil, and obtaining thereby a unit of material and (see Fig. 10). By weighing the soil and then determining the amount of water that it holds, the amount of absolutely dry soil may be ascertained. Dividing this by the weight of an equal volume of water gives the apparent specific

¹ For Whitney, M. Some Physical Properties of Soils (U. S. D. A., Washington, D. C., 1905).

specific for that soil. A laboratory determination may be made by putting the soil into a weighed and known volume, and weighing it. From the weight of the substance displaced and the weight of an equal volume of water, the apparent specific gravity may be calculated. This method will give only approximate results, however, as the structural relationships are more or less artificial. The only reliable method is the one first described.

83. **Actual weight of a soil.**—With the apparent specific gravity of a soil known, its weight in pounds to the cubic foot may be found by multiplying by 62.52. Soils may vary in weight from 65 to 80 pounds for clays and silts to 100 to 140 pounds for sand. The greater the humus content, the less is the weight to the cubic foot. A rock soil often weighs as little as 15 or 20 pounds. The weight, of course, is for absolutely dry soil and does not include the water present, which may be much or little, according to circumstances. The actual weight of a soil is often expressed in *tonne-feet*. An *tonne-foot* of soil refers to a volume of soil one acre in extent and one foot deep. In the same way we may have an *acre-foot* of soil or an *acre-centimeter*. The weight of an acre-foot of soil usually varies from 7,000,000 to 4,000,000 pounds; granulation and organic matter may modify this considerably. The value of knowing the actual weight of a soil lies in the possibility of calculating thereby the amount of water, the amount of humus, or the actual number of pounds of the mineral constituents present in the soil. Such information affords a ready means of comparing two soils with their corresponding capabilities.

84. **True space in soil.**—The pore space in soil is due largely to structural conditions. As already mentioned, the closer the soil, the smaller is the aggregate

amount of internal space. *Pods* individual space is larger under each condition, and this accounts for the ready movement of water and air through such soils. A clay soil, while exhibiting a very large amount of pore space, has the disadvantage of very minute individual pores. The large amount of space occurs because of the lightness of the particles and the tendency toward granulation. The small size of the individual space is a direct function of size of particle, or texture.

A very simple formula may be used for a determination of the percentage of pore space in any soil, provided the absolute and the apparent specific gravities are known:—

$$\text{Percentage of pore space} = 100 - \left[\frac{(\text{Ap. Sp. Gr.}) \times (100)}{(\text{Ab. Sp. Gr.})} \right]$$

Thus a soil having an apparent specific gravity of 1.10 and an absolute specific gravity of 2.65 has 58.5 per cent of pore space; while in a soil in which the above figures are 1.10 and 2.51, respectively, the percentage of pore space is 56. The following figures, taken from King,¹ illustrate the relation that texture holds to total pore space in soils:—

| | PERCENTAGE OF PORE SPACE |
|---------------------------|-----------------------------|
| Sandy soil | 52.50 |
| Loam | 56.60 |
| Heavy loam | 46.75 |
| Loamy clay soil | 45.22 |
| Clayey loam | 47.10 |
| Clay | 48.00 |
| Very fine clay | 43.84 |

¹ King, P. B. *Physics of Agriculture*, p. 154. Published by the author, Worcester, 1924.

The pore space in any of these soils is, of course, subject to considerable fluctuation, especially in the surface soil, due to tillage and the incorporation of organic matter; hence a fairly keen sight to the certain conditions needed more pore space than a till or a clay loam. When soils are in the physical condition for the best plant growth, however, the rule holds that, the finer the soil, the greater is the pore space. The differences in pore space between the surface soil and the subsoil in Wisconsin are shown by King¹ as follows:—

| | Volume as Laid Down | Percentage as Laid Down |
|-----------------------|------------------------|----------------------------|
| Plut. loam | 740 | 52.3 |
| Forest loam | 525 | 44.9 |
| Chalk loam | 350 | 35.8 |
| Plut. loam | 325 | 35.8 |
| Plut. loam | 172.5 | 32.8 |
| Chalk loam | 111.7 | 32.8 |

The pore space in a neutral soil is occupied by water and air. If the water content is low, the air space is large, and vice versa. Thus the relationship of the total pore space and the size of the individual spaces to the amount of air and water contained, by their movement through the soil, to soil aeration, to root extension, to bacterial action, and to crop yield is general, hence apparent. It is the regulation of this pore space that is really studied in any structural consideration. The effect on plant growth of a change in pore space is the final test of its availability.

¹ King, P. H. *Physics of Agriculture*, p. 114. Published by the author, Madison, Wisconsin, 1905.

86. The number of soil particles.—The number of particles in any given volume of soil is really determined by chance, and, as this number determines very largely the probable arrangement of the soil grains, structure becomes in turn dependent on the size of grains. Since soil particles run to very small dimensions, the number in any given volume is very large, especially when we are dealing with fine-textured soils or with soils of some past structural condition. Any calculation of the number of particles present in a soil is open to considerable inaccuracy, first, because it is impossible to get a correct figure for the average diameter of the particles of any soil or of the various groups of separates that go to make it up, and, secondly, because it must be assumed in the calculation that the particles are spherical. This assumption is of course incorrect, as has already been demonstrated; but it must be extended in order to obtain approximate ideas as to the number of grains in any soil.

The number of particles in any soil sample may be arrived at from a mechanical analysis soil the diameters that limit each group. Using the average diameter of each group together with the percentage of the group in a given sample, the number of particles may be calculated by the following formula:—

$$\text{Number of particles in a sample of soil} = \frac{\text{Weight of sample in grams}}{1/6 \pi D^3 \times 1.20}$$

The formula $1/6 \pi D^3$ is that used for determining the volume of a sphere, the diameter in this case being expressed in centimeters. The volume of the sphere, then, is obtained in cubic centimeters, which must be multiplied by the absolute specific gravity of soil minerals, or 2.65,

is water that the weight in grams of a single cell grain may be obtained. A molecular by this method of the number of particles in a sample from a given below:—

| Sample No. | State | Volume in Terms of Cells or Grains per Unit Volume | No. of Cells or Grains per Unit Volume | | Approximate Volume of Sample in Cells |
|------------|-----------|--|--|-----------------|---------------------------------------|
| | | | 10 ⁶ | 10 ⁹ | |
| Range of | | | | | |
| of | 2-1 mm. | 200 | 1 | | 9 |
| Change | | | | | |
| and | 1-5 mm. | 1,000 | 4 | | 17 |
| Medium | | | | | |
| and | 1-25 mm. | 12,400 | 25 | | 3,300 |
| Base | | | | | |
| and | 25-40 mm. | 23,900 | 25 | | 6,100 |
| Very fine | | | | | |
| and | 10-15 mm. | 1,670,000 | 50 | | 200,000 |
| 44 | 10-15 mm. | 2,000,000 | 10 | | 2,000,000 |
| 45 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 46 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 47 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 48 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 49 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 50 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 51 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 52 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 53 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 54 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 55 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 56 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 57 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 58 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 59 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 60 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 61 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 62 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 63 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 64 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 65 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 66 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 67 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 68 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 69 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 70 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 71 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 72 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 73 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 74 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 75 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 76 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 77 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 78 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 79 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 80 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 81 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 82 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 83 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 84 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 85 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 86 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 87 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 88 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 89 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 90 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 91 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 92 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 93 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 94 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 95 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 96 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 97 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 98 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 99 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |
| 100 | 10-15 mm. | 2,000,000 | 5 | | 1,000,000 |

A very great error is introduced by this method, especially in assuming that the average size of particles for the ray spreads is 0.025 millimetres. As the ray particles may become molecular complexes and consequently are very, very small, it stands to reason that such an assumption is far from correct. Nevertheless, it gives a very good idea as to the immense number of grains that we have to deal with, even in the context of milk. A few figures as to the approximate number of particles in various samples and shares of the United States¹ as reported by the Bureau of Soils, are given below:—

¹ For methods of analysis of the above, see Chapter VI, p. 116.

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APPROXIMATE VOLUMES OF PARTICLES IN THE GRAIN OF
VARIOUS CLASSES OF SOILS IN THE UNITED STATES

| Class | Approximate Volume of Particle |
|---------------------------|-----------------------------------|
| Coarse sand | 2,200,165,000 |
| Small | 2,207,451,864 |
| Fine sand | 1,624,079,995 |
| Sandy loam | 5,093,707,000 |
| Very sandy loam | 5,095,000,117 |
| Loam | 7,145,079,962 |
| Silt loam | 5,095,166,066 |
| Very silty | 13,828,064,000 |
| Clay loam | 11,877,879,000 |
| Silty clay loam | 11,400,107,000 |
| Clay | 10,077,571,000 |

88. Surface exposed by soil particles. - Besides giving an actual numerical figure and no insight into the probable structural relationships of a soil, the approximate number of particles may serve still another purpose - that of enabling us to calculate the aggregate internal surface exposed by the soil grains. The surface of the grains held more or less water according to their size, and they increase the amount of chemical and biological activities - functions so necessary to a continuous replacement in the soil solution of the elements withdrawn by the plant. The minerals in the soil are all very resistant to solution; if they were not, they would long ago have been leached away. Such materials, while almost insoluble, allow the movement of material going into solution to be notably increased by friction of water, although their solubility remains the same. The increase of the particles, then, presents another significant feature besides those already pointed out.

Another important property of the surface of the gray is the tendency toward the adsorption of soluble material in a partially or wholly suitable condition for plant use. This power, designated as adsorption, is not exhibited to a high degree by fine soils, in which the individual pore spaces are small and the amount of surface exposed is large. It is an important factor to be observed in the addition to the soil of soluble fertilizing constituents. Adsorption may also, by bringing materials into closer contact, hasten or retard certain chemical actions. Reactions may thus be expected to go on in the soil that would not take place in the laboratory beaker. The relation of this adsorption to bacterial activity also cannot be overlooked.

The aggregate area presented by soil particles is very large, even for the coarse soils. With the finer soils, because of the immense number of particles, a figure is reached that is almost beyond comprehension. When the approximate number of particles and their mass in any given weight of soil are known, the internal surface may be calculated by the following formula:—

$$\text{Surface} = n \cdot D^2 \times \text{number of particles}$$

As the estimation of the number of particles in a soil is so inaccurate, it is evident that a calculation of the surface exposed based on such a figure must be more or less an error.

However, to give some idea of the internal surface exposed by ordinary soils, the calculations made in a few of the average soil classes of the United States, already presented,¹ are given in the table on the following page.

¹ See Chapter VI, p. 126.

APPROXIMATE SURFACE AREA, MEASURED BY AVERAGE CUBES,
 OF CLAYEY PEAT-BLUE ROLES

| | Number of Cubes per Role | Surface Area per Cubic Foot | Surface Area of Average Role in Square Feet |
|----------------------------|-----------------------------|--------------------------------|---|
| Clayey peat-blue | 81 | 298 | 24,138 |
| Peat-blue | 59 | 269 | 15,891 |
| Peat-blue | 75 | 242 | 18,150 |
| Clayey peat-blue | 210 | 171 | 35,910 |
| Peat-blue | 202 | 169 | 34,138 |
| Peat-blue | 194 | 157 | 30,462 |
| Peat-blue | 187 | 157 | 29,386 |
| Peat-blue | 171 | 153 | 26,157 |
| Clayey peat-blue | 154 | 145 | 22,130 |
| Clayey peat-blue | 142 | 142 | 20,157 |
| Clayey | 139 | 139 | 19,157 |

It is at once apparent that the amount of surface exposed by the soil grains of even a good is enormous. It is not to be wondered at that the slowly soluble minerals are able to supply sufficient food to the crop growing on them, when such a large amount of surface is continually available for chemical action. The figures presented for an acre-foot of soil are almost too large for adequate comprehension. It is quite evident that the finer the soil, the greater is the amount of internal surface. For example, a sandy loam weighing 90 pounds to the cubic foot would present 81,000 square feet of surface, while a clay weighing 75 pounds to the cubic foot would expose about 154,000 square feet. This is equivalent to 1.28 and 2.84 acres, respectively.

57. The effective mean diameter of soil particles. It is very evident that the calculations presented above, both as to the number of particles and as to the internal

surface exposed, are far from correct, as we can arrive at a definite figure as to the composition of grain. Neither do we know the actual structural conditions. In considering these uncertainties King² decided that we were in need of a single term which not only would give an indication regarding the size of grain, but also would carry with it definite ideas as to the arrangement of the particles, particularly as to the size at which they would alter in and under to pass through. This would bring the considerations nearer to the plant, as permeability very largely determines the conditions for plant development. King, while he could obtain neither the mean diameter of particle nor the actual internal surface, found that he could determine with considerable accuracy, particularly in sandy, the diameter of grain which if substituted for the actual one would permit under the simulation the same rate of air and water movement. This size of grain he designated as the effective mean diameter of particle for that particular soil.

The theory of the method is presented by Scholten³ and is based on the flow of fluids through capillary tubes. From the observed rate of the flow of air through a soil column under controlled conditions, it is possible to calculate the effective diameter of the interstitial space. From these data the size of the spherical grains which would be necessary to have such porosity, or capillary tubes, is computed by appropriate formulae. Such a figure represents the effective mean diameter of the soil.

¹ King, F. E. *Physics of Agriculture*, pp. 119-120. Published by the author, Madison, Wisconsin, 1901.

² Scholten, C. S. *Theoretical Investigation of the Movement of Gaseous Vapors*. U. S. Geol. Survey, 1902, Ann. Rept., Part II, pp. 211-266, 1920.

from which the effective surface exposed can be determined. Thus, designating a soil as having an effective cone diameter of particle of 0.053 millimeter merely indicates that this particular soil shows an air and water movement the same as would be shown by a homogeneous soil with spherical particles of this diameter.

The apparatus¹ for the determination consists of a cylinder in which is placed a sample of air-dry soil, the pore space being carefully determined by weighing. The rate of air movement is then determined by connecting with an analyzer, the temperature and the pressure being continuously under control. The readings usually calculated is a temperature of 27°C. The fact that the structural condition of the soil is likely to be disturbed in placing the sample in the apparatus tends to detract from the accuracy, especially in fine soils. Nevertheless,

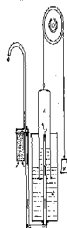


FIG. 24.—King's apparatus for the determination of the rate of air movement through soils. (A), pressure gauge; (B), soil column; (C), water; (D), manometer; (E), weight.

King found his results fairly accurate, and showed that the calculated rate of the several flow of water through

¹ King, P. H., *Properties and Conditions of the Movement of Unsat. Water*, U. S. Geol. Survey, 1916 Jour. Recl., Vol. 11, pp. 225-241, 249. A complete discussion is given of King's ideas in this article, pp. 27-296.

which agreed rather closely (see Fig. 33). The effective diameter of the particles varied of course with, together with the effective surface exposed, is given below.¹

| Soil | Effective Diameter | Effective Surface per Gram of Soil | Effective Area of One Gram of Soil |
|-----------------------------|--------------------|------------------------------------|------------------------------------|
| Recent sandy soil | 2420 μ m. | 36.9 | 8310 sq. μ . |
| Sandy soil | 4050 μ m. | 36.5 | 13,620 sq. μ . |
| Sandy loam | 4520 μ m. | 36.5 | 16,620 sq. μ . |
| Loam | 5210 μ m. | 44.1 | 40,510 sq. μ . |
| Heavy clay soil | 2010 μ m. | 55.7 | 75,310 sq. μ . |
| Very clay soil | 1030 μ m. | 58.9 | 110,020 sq. μ . |
| Very fine clay | 450 μ m. | 123.9 | 177,770 sq. μ . |

The method of King has certain advantages, besides giving an idea as to the number of particles, their internal surface, and the relation of this internal surface to soil conditions. In the first place, a single figure is used to represent the size of particle; secondly, from this effective size of particle the probable rate of air and water movement may be estimated; and, thirdly, the number of particles and the internal surface calculated therefrom have a fairly definite relationship to the plant, as such figures are so closely correlated to the condition of air and water.

¹ King, F. B. *Physics of Agriculture*, p. 233. Published by the McGraw-Hill Co., New York, 1912.

CHAPTER VIII

THE ORGANIC MATTER OF THE SOIL

One of the essential differences between a soil and a mass of rock fragments lies in the organic content of the former. Organic matter is a necessary constituent in order that freely grown mineral material may be designated as a soil and that it may grow *successfully*. Physical conditions depend largely on the presence, and chemical reaction is greatly accelerated by the decay, of organic matter. In the process of soil formation its addition is more or less a secondary step. Its gradual decline the amount of organic matter held by the growing soil increases as the process of weathering goes on; in *glacial soils*, however, the matrix, or skeleton of the soil, is already formed before there is any opportunity for humus to become incorporated therein. The final result from the mixing of the materials carrying numerous weathered and altered products with the decayed or partially decayed organic matter that is now in accumulation must be a mass much more complicated than either of the original constituents. It is hardly necessary to further emphasize the complexity of the average soil, the various disorders, and the difficulties in studying the question.

88. The source and distribution of organic matter. — The source of practically all soil organic matter is plant tissue. Some of this matter accumulates from the above-ground parts of plants that have died and fallen down

to become united with the surface soil; the remainder is a result of root extension and subsequent decay. The organic matter of the surface soil is derived from the tops and the roots of plants growing on it, while that of the subsoil is very largely a result of root extension and subsequent decomposition. The relationship between the former method of three soils and the roots developed is shown by the following data presented by Kostycheff¹ and quoted by Hilgard² and Webber³:

Root Extension and Decomposition of Grass in Three
Diverse Soils

| Years Grown | 1 | | | 2 | | | 3 | | |
|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | Roots | Grass | Stems | Roots | Grass | Stems | Roots | Grass | Stems |
| 6 | 100 | 2.6 | 990 | 82 | 100 | 82 | 100 | 1.5 | 1.5 |
| 12 | 80 | 4.8 | 86 | 5.9 | 80 | 80 | 100 | 2.2 | 2.2 |
| 18 | 87 | 2.6 | 48 | 3.6 | 70 | 67 | 100 | 6.7 | 6.7 |
| 24 | 47 | 2.5 | 35 | 2.8 | 35 | 5.6 | 100 | 5.6 | 5.6 |
| 30 | 47 | 2.5 | 20 | 2.7 | 35 | 1.6 | 100 | 1.6 | 1.6 |
| 36 | 35 | 1.8 | 34 | 1.6 | 32 | 1.7 | 100 | 1.7 | 1.7 |
| 42 | 26 | 1.2 | 9 | 5 | 18 | 1.5 | 100 | 1.5 | 1.5 |
| 48 | 11 | .8 | | | | | 100 | | |
| 54 | 7 | .8 | | | | | 100 | | |

86. *Composition of plants*.—It is usual, in classifying the materials comprising plant tissue, to group them under three heads—mineral matter, fibre and oil, and proteins.

¹Kostycheff, M. D. *Les Terres Végétales Russes*. *Annales de l'Institut de Chimie*, tome II, pp. 115-121. 1887.

²Hilgard, E. W. *Soils*, p. 116. New York. 1896.

³Webber, G. *The Structure for Organisms*, p. 116. Philadelphia. 1897.

The carbohydrates, having the general formula of $C_n(H_2O)_m$, include such compounds as glucose, starch, cellulose, dextrin, cane sugar, and the like. The fats and oils may be represented in plants by such glycerides as lecithin, stearin, olein, palmitin, and the like. The proteins are by far the most complicated of the three principal compounds, as they may carry not only carbon, hydrogen, oxygen, and nitrogen, but also inorganic elements such as sulfur, phosphorus, iron, zinc, and other elements. They are compounds of high molecular weight and are mostly of proteic constitution. Simple proteins, such as albumin, globulin, protosin, and others, are found in plants, besides certain derived proteins such as proteases and peptases. In addition to all these, there is a host of other compounds that have so small influence on the composition of the soil organic matter. Among these are the alkaloids, gums, tannins, pectins and their derivatives, hydrocarbons, resins, waxes, aldehydes, and others.

The original plant tissue, therefore, while fairly well known, as to chemical constitution, is far from simple. The degradation of such material, especially in the presence of simple mineral products, will evidently give rise at first to compounds so simple. In fact, the chances are that the resulting compounds will be much more complicated. It is only later in the presence of decay that simple products result.

66. Decay of organic matter in soils. From the fact that weathering is regarded as a process of simplification, and since it is evident that the plant tissue, as it enters the soil is so very complex, the general change that the organic matter undergoes must be one of simplification. This simplification, however, is very slow, and many of

the products built up are more complex than the original *source*. Most of this decay and simplification is due to that great group of organisms so universally present in soil, called bacteria. Some of these are parasitic in their action, while others feed to a large extent with the products of the decomposition. All, however, exert a general *simplifying* influence. The action of such organisms tends to direct, but is more likely to be unguided in its nature, and may take place either within or outside of the soil. A cycle is therefore set up in which the higher plants and animals are occupied in building up, while bacteria are busied down and reducing the results of plant action to simple forms, such as can be ultimately utilized again in plant nutrition. The great importance of bacteria is thus evident, and the management of their growth and function is clearly a part of good soil management.

When the complex molecules that make up plant tissue break down, they split along definite lines of cleavage, depending on the structure of the original molecule. These bodies, which are usually simpler in nature than those from which they have sprung, are called *decomposition products*, and without a doubt they are the primary products of the first step in organic decay. These compounds are subject to still further change, and because of the great number of agencies at work the secondary products that result may be simpler or more complex, according to conditions. Bacteria have a tendency, while having down organic matter, to condense certain built-up products which present a very complicated molecular build-up into simpler forms. The secondary products therefore vary widely because of differences in temperature, moisture, aeration, and other conditions.

The character of the secondary products probably is linked a greater measure than does that of the original plant tissue. In the process of decay these products become black or brown in color, and are usually designated as humus materials in the soil. Organic matter, then, covers all the material of organic origin in the soil, and may refer not only to the original plant tissue, but also to that which has lost its identity in the secondary products. Hence refers specifically to the primary and the secondary products of decay, and may be simple or complex, according to conditions.

In the process of decay gases are certain and products result. These are probably mild and partially gaseous. Carbon dioxide is a universal product of bacterial activity of all kinds, as is also water. Besides these, urea, ammonia, nitrites, and nitrites may result from nitrogenous decay. The flow general changes of organic matter found in soil may be illustrated by the following diagram:

| PLANT TISSUE | HUMUS | SOIL PRODUCTS |
|----------------|-------------------------|---------------|
| ORGANIC MATTER | ORGANIC AND ORGANICALLY | SOIL PRODUCTS |

FIG. 11.—Diagram illustrating the flow general changes of organic matter found in soil.

It is therefore possible to have general, besides the original organic compounds which are mostly of plant origin, not only their primary and secondary degradation products, but also compounds either new down or built up from those. An attempt to enumerate even the original compounds in the plant tissue, or even the simple end products of complete decay, would result in a long list of materials representing almost every known class of organic compound. Such a procedure is possible, but is unnecessary as the important ones have already

have mentioned. It is to be kept in mind that the simple products of decay are the ones utilized by crops, although it is a well-established fact that some of the secondary and intermediate compounds may be taken up by certain plants and probably are of some importance from the standpoint of taste and food.

9. *Composition of the soil humus*.—It is evident that the most complicated parts of the organic matter in the soil are the primary and the secondary products of decay, or the so-called soil humus. The study of this matter is difficult and calls for the very highest knowledge of organic chemistry. This is true for two reasons: first, because of the complexity of these compounds; and, secondly, because they are continually changing. A serious accountant present in the soil one month may be absent the next week. However, while some of the soil humus is soluble in water and may circulate in the soil solution, the bulk of it is insoluble. This is itself presents difficulties. When the soil humus is treated with the various extractive agents, reactions may be induced which would not take place in a normal soil. Compounds are thus formed which not only would be abnormal, but would probably not exist under natural conditions.

A great many chemists have worked on the problem of the constitution of the organic matter of the soil and have published their results. The ideas of the early workers are fully embodied in the concluding statement by Mulder¹ who was in many ways far in advance of his

¹ Mulder, C. J. *Die Organischen Verbindungen im Boden*. *Chemie der Bodenkrumme*, 1, pp. 235-253. Berlin, 1855. Also, *Wien, E. W. Agricultural Analysis*, Vol. 1, p. 43. Paris, 1856.

tion. Muller concluded that the organic matter consisted of seven distinct compounds as follows:—

- 1 and 2. Utric acid and Utric 5. Uric acid
- 3 and 4. Utric acid and Utric 6. Aqueous acid
7. Utric acid

These bodies he considered as arising from mesomorphs by oxidation; thus, uric acid ($C_4H_4N_4O_6$) gave uric acid ($C_4H_4N_4O_6$), which in turn yielded uric acid ($C_4H_4N_4O_6$), followed by uric acid ($C_4H_4N_4O_6$) and finally by uric acid ($C_4H_4N_4O_6$). Such a chain of oxidation seems very simple, but certain lines are at once noticeable. In the first place, although does not find a place in any of these formulae; secondly, the compounds are simpler than most plant tissues, which is not what would be expected, especially with some of the degradation compounds; thirdly, none of these products have united with the bases in the soil, a reaction that would be very likely to take place especially with uric compounds. None the investigations¹ of Muller's have obtained dissonant results, but these were explained for the time being by assuming that the decomposition occurred because of added molecules of water.

Later investigations, while producing only slightly better results, did nevertheless cast some doubt on the old ideas of the Muller school of chemistry. This again opened up the question as to the composition of the soil organic matter, especially the humic constituents. Thus, while it is evident that no such compounds as uric

¹ See Steiner, G., and Steiner, R. C. The behavior of humic organic substances from soils. *J. A. C. S.*, Vol. 60, No. 2, pp. 35-46, 1938.

acid, humic acid, or carbonic acid exist in the soil, one may see pointed out in soil literature that of humus and humic acid. The word humus, as already intimated, does not relate to any definite compound, but to the great mass of primary and secondary products of biological and chemical organic decay taking place in the soil. One of the men whose work established beyond a doubt the fact that humus was not a definite compound was Van Bemmelen.¹ His investigations still further showed that the soil humus was largely in a colloidal condition, and therefore exhibited properties quite distinct from those shown by crystalline solids.

In recent years investigation has again been directed toward the immense field opened up by the creation of the *Zeitschrift* edited by Ruzsinsky,² by his researches, hitherto hardly paralleled in nature, in porous properties which are largely colloidal in nature. Among these characteristics are high water capacity, great adsorptive power for certain salts, ready reaction with other colloids, power to decompose salts, great shrinkage on drying, and swelling in the presence of electrolytes. Joliet³ has studied the composition of the adsorbable organic nitrogen in peat and in mineral soils. The nitrogen was generally then obtained and he divided into the following groups:—

¹ Van Bemmelen, J. M. *Die Abbauprodukte der organischen und der Abbauprodukte der organischen Substanz*. Van Nostrand Publ., Book 33, Seite 97-110, 1895.

² Ruzsinsky, L. *Zeitschriften über die Humusstoffe*. Joliet, J. C. *Zeitschriften über die Humusstoffe*, Seite 97-110, 1895.

³ Joliet, J. C. *Organic Nitrogen Compounds in Peat*. Jour. Mich. Agr. Exp. Sta., Publ. No. 4, November, 1906. Also, *The Chemical Nature of the Organic Nitrogen in Soil*. Jour. Agr. Res., Research Pub. 1, June, 1913.

- | | |
|------------------------|--------------------|
| 1. Nitric nitrogen | 3. Diamine acids |
| 2. Ammoniacal nitrogen | 4. Amino acids |
| | 5. Monoamino acids |

The two latter coefficients were found to make up the bulk of the organic nitrogen, but quantitative determinations proved uncertain. These compounds produced various results, the rate depending on their chemical structure.

54. **The work of Oswald Schröder.**—Of the chemists who have been most active and most successful, Schröder¹ (Hamburg) is the most. Our present knowledge of the chemical constitution of the organic matter of the soil is very largely due to his efforts. While he realized that the isolation of specific compounds from the soil was likely to present insurmountable problems, and that the classification of such compounds after they were obtained might be very difficult, he undertook a systematic extraction of the soil. As a result of several years of work he was able to isolate soil directly a number of compounds. The complexity and varied character of these compounds is revealed by the following list of the more important bodies isolated:—

See **ON COMPOUNDS ISOLATED FROM SOIL**. ONSWALD, **MITTEIL. VON SCHWEDEN, (HAMBURG, SCHWEDEN, 1888), AND OTHERS**, NO. 111. N. HENRIOT ET SOUS.

| | |
|-----------------------------|----------------------------|
| Nitrobenzenes, $C_6H_5NO_2$ | Pinoline, carbonylic acid, |
| Dihydroxybenzoic acid, | $C_{12}H_{11}O_3N$ |
| $C_{10}H_7O_4$ | Hexamine, $C_6H_{12}N_6$ |

¹Schröder, B., and Rother, E. C. The Isolation of Natural Organic Substances from Soils. Vols. I, II, III, IV. See Soils, Ed. 2, 1903, also Data 47, 73, 94, 117, 131, 141, 157, 168, and 191.

| | |
|--|--------------------------------------|
| Mandelic-acetic acid, $C_{10}H_{10}O_4$ | Aspirin, $C_9H_8O_4$ |
| Ascorbic acid, $C_6H_8O_6$ | Cytosine, $C_4H_5ON_3$, H_2O |
| Aspartic acid, $C_4H_7NO_4$ | Xanthine, $C_5H_4N_4O_6$ |
| Butyric acid, $C_4H_8O_2$ | Hypoxanthine, $C_5H_4N_4O_6$ |
| Caproic acid, $C_6H_{12}O_2$ | Uric acid, $C_5H_4N_4O_6$ |
| Caproic-acetic acid, $C_{10}H_{18}O_4$ | Adenine, $C_5H_5N_5$ |
| Pyruvic acid, $C_3H_4O_3$, H_2O | Caffeine, $C_8H_{10}N_4O_2$ |
| Formic acid, $C_1H_2O_2$ | Thymine, $C_5H_8N_2$ |
| Oxalic acid, $C_2H_2O_4$ | Quinine, $C_{20}H_{24}N_2O_5$ |
| Succinic acid, $C_4H_6O_4$ | Cocaine, $C_{17}H_{21}NO_4$ |
| Succinic acid, $C_4H_6O_4$ | Cocaine, $C_{17}H_{21}NO_4$ |
| Acrylic acid, $C_3H_4O_2$ | Nicotic acid (pyridine nicotinic) |
| Malic acid, $C_4H_6O_5$ | Cellulose, $C_6H_{10}O_5$ |
| Phenol, C_6H_6O | Cellulose, $C_6H_{10}O_5$ |
| Schiff's aldehyde, C_6H_5CHO | |

From a chemical standpoint these compounds may be divided under five heads: (1) those containing carbon and hydrogen; (2) those containing carbon, hydrogen, and oxygen; (3) those containing carbon, hydrogen, and nitrogen; (4) those containing carbon, hydrogen, oxygen, and nitrogen; (5) those containing sulfur in combination with the elements listed above. With the possible presence in each of compounds containing five elements, it is of little wonder that the subject is a complicated one. It is evident, moreover, that the list given above is only a partial one, and many other compounds of an even more intricate composition will later be added.

So far as the present is concerned, the compounds may be divided into three groups—those that are beneficial, those that are neutral, and those that are toxic or harmful, in their effects. As an example of the first group,

hormone and emulsion¹ may be mentioned. There is a case in which the compounds found in the soil horser may exert a stimulating effect on plant growth, and may also be a source of phosphate, supplementing the nutrient² to a certain extent. That the nitrogen of the soil organic matter may be utilized by plants is well understood by the publications of Hitchcock and Miller.³ As an example of a lactic acid compound arising from the decomposition of the organic matter, ethylhydroxybutyric acid⁴ may be mentioned as one of the lactic acids. This compound was the first to be isolated and identified by Sabinin, and is very toxic.

It is even suggested by this author, "The discovery of such compounds in the soil has verified the old theory of humus" by which the fertility of soils with it accounted for. These suggestions are also held to be fundamental to succeeding crops of the same kind. The

¹Hitchcock, J. J. *Effect of Hormones and Arginine on Soil Conditions*. *British Internal Chem. Soc. Trans.*, Vol. XX, pp. 355-366, 1922. Also, *Journal of Chemical and Chemical in General*, *Brit. Chem. Soc.*, Vol. 50, No. 3, pp. 157-165, 1922.

²Sabinin, O., and Miller, J. J. *Microscopic and Chemical and Their Bearing upon Soil Fertility*. U. S. D. A., *Div. Soils*, Bul. 87, p. 10. (1912). Also, Sabinin, O., and Miller, J. *Journal of Chemical and Chemical in General*, *Brit. Chem. Soc.*, Vol. 50, No. 3, pp. 157-165, 1922.

³Hitchcock, J. J., and Miller, N. H. J. *The Direct Assimilation of Inorganic and Organic Matter of Nitrogen in the Soil*. *Trans. Amer. Soc. Agr. Sci.*, Vol. 4, Part 1, pp. 282-307, 1912.

⁴Sabinin, O., and Sabinin, J. J. *New Methods of Nitrogen in the Soil*. *Trans. Amer. Soc. Agr. Sci.*, Vol. 4, Part 1, pp. 282-307, 1912.

⁵See Sabinin, O., and Sabinin, J. J. *New Methods of Nitrogen in the Soil*. *Trans. Amer. Soc. Agr. Sci.*, Vol. 4, Part 1, pp. 282-307, 1912.

soil materials of the soil interior largely originate under conditions of poor drainage and aeration, and consequently are biological in their genesis. The toxicity of such compounds as dihydroxybenzoic acid, picolinic carboxylic acid,¹ and aldehydes² may therefore be erroneously ascribed,³ as that good soil aeration is a factor in dealing with such conditions. Inefficient aeration of the soil seems to account very largely for the presence of soil poisons. Furthermore, according to Kistner and Blumel⁴ water is known to increase the harmful effects of such compounds; nitrogenous fertilizers converting some toxic materials, and phosphorus or potash neutralizing others. For example, in water solution and sand culture, nitrogen seems especially effective in converting such toxic substances as dihydroxybenzoic acid and oxallic, phosphorus is particularly powerful in counteracting cyanide, and potash has considerable influence on spores.

While the real importance of the bio-chemical germinal in the soil cannot be fully discussed at this point, it is quite evident that such micro-organisms do tend to develop under anaerobic conditions and must be considered in

¹Kistner, O., and Blumel, J. J. The Inhibition of Microbial Degradation of Nitrate from Soil. U. S. D. A., Bur. Soils, Bul. 25, pp. 45-48, 1930.

²Kistner, O., and Blumel, J. J. Harmful Effects of Aldehydes in Soil. U. S. D. A., Bul. 191 (Technical Paper), 1934.

³Kistner, O., and others. Possible Degree of Concentration of Soil in relation to Soil Fertility. U. S. D. A., Bur. Soils, Bul. 42, p. 13, 1935. Also, Kistner, O., and Bond, H. B. The Role of Cyanide in Soil Fertility. U. S. D. A., Bur. Soils, Bul. 66, p. 32, 1936.

⁴Kistner, O., and Blumel, J. J. Organic Compounds and Soil Fertility. U. S. D. A., Bur. Soils, Bul. 77, 1931.

the discussion of the composition of that great group of intermediate compounds, which forms among them the decay of the organic matter of the soil. While Gildersleeve found twenty acids out of a group of sixty taken in various States of this country, to contain diphosphoric acid, this does not necessarily mean that this compound in itself is a serious detrimental factor. It is very likely that such compounds are merely products of improper soil conditions, and are to be considered as concomitants with depressed crop yields. When such conditions are righted, the so-called toxic matter will disappear. Good drainage, lime, tillage, a balanced food action, proper rotation and mulching, are so efficacious in the regard that permanent soil toxicity need never be feared by the farmer.

94. *Bad products of human sewage.*—In the processes of chemical and biological decay of the soil organic matter present, the simple compounds already noted begin to appear. This change is of course correlated with a certain amount of qualitative action, but compounds thus built up must ultimately succumb to the agencies of work and suffer a splitting-up and reduction to simple bodies. Carbon dioxide is one of the most important of these compounds, being always a product of bacterial activity. Its importance has already been noted in the discussion of mulching. Here it heightens the solvent power of water and tends to increase the amount of plant-food carried in the soil solution. Guttation is a direct result of its presence. Carbon dioxide may also tend to flocculate colloidal matter in soils, and thus benefit the physical condition. With increased organic matter in any soil, there greater bacterial action will as increase in the carbon dioxide evolved very well be expected. It

fact, the carbon dioxide production of a soil is considered by many authors¹ to be a measure of bacterial activity. With this increase in carbon dioxide the soil air-bodies were heavily charged and an alteration in bacterial and plant relationships may thereby be induced. The following figures, by Volley,² show the composition of the soil atmosphere and the effects of additional humus material on the carbon dioxide content:

| | Percentage of Volume of | |
|--|-------------------------|----------------|
| | CO ₂ | O ₂ |
| Soil air (average of 10 samples) | 3.84 | 10.23 |
| Humus-soil | 24 | 20.18 |
| A sandy soil | 1.05 | 15.72 |
| A sandy soil plus manure | 9.75 | 13.25 |

While carbon dioxide may be evolved by the splitting-up of both carbohydrate and nitrogenous bodies, ammonia results only from the latter. It is really the first extremely simple nitrogenous body produced. It can be utilized by some plants as a source of nitrogen, as it also does with certain simple lactic bodies, but ordinarily it must undergo oxidation. This oxidation results in nitrous (NO₂) and ultimately in nitric (NO₃), the latter being usually considered as the chief source of the nitrogen utilized by plants.

¹ Nielsen, J., and Peters, A. *Ueber die Eigenschaften des Ammon, und die Bedeutung des Natriumammoniums im Boden*. *Chemik. Zeits.*, 11, 14, 816-725, 1903.

² Volley, E. *Die Gärung des Organischen Stoffes*. Berlin, 1897.

Other end products, such as methane (CH_4), hydrogen disulfide (H_2S), free nitrogen (N_2), sulfur dioxide (SO_2), carbon dioxide (CO_2), and the like, may also result. They are relatively unimportant, however, as regards the plant, in comparison to the role played by carbon dioxide, ammonia, the nitrates, and the nitrites. The production of the nitrates from ammonia, particularly is very closely connected with good soil conditions, especially optimum moisture and adequate aeration. The proper handling of the soil, then, not only will tend to eliminate their further and prevent its further formation, but will encourage the proper decay of the soil humus and the production of end products which will function directly or indirectly as plant foods.

Styler¹ found that when humus was associated with an alkali and then precipitated with an acid, it yielded from five to twenty-five per cent of a whitish brown ash. This ash contained silica, iron, and alumina, as well as magnesia, potash, phosphates, sulfur, sodium, and calcium. While part of these mineral constituents may be directly combined with humus, it is probable that some may be present because of the absorptive capacity of the organic colloids which are always present in humus generated under normal conditions. Styler has estimated that in an ordinary soil containing a fair amount of organic matter, one-third of the phosphorus and one-twelfth of the potash may be present in such a state. They are then fairly available, and are yielded much more readily to the plant than if of a strictly inorganic nature.

84. *Chemical materials of soil.*—After the extraction of the soil for the study of the ordinary humus com-

¹ Styler, Henry. *Production of Humus from Manure*. *Michigan Agr. Exp. Sta. Bul. 33*, pp. 25-26. 1907.

glands, a considerable mass of material remains, which is available to water, alkali, and other ordinary reagents. By the extraction of a large amount of soil, Schreiner¹ was able to study this material. He found it susceptible to division into six groups, as follows: (1) plant tissue, (2) insect and other organic material, (3) charcoal particles, (4) lignites, (5) coal particles, and (6) materials resembling natural hydrocarbons, as bitumen, asphalt, and the like. Such material was found not only near the surface of the soil, but at depths of fifteen or twenty feet below. All the groups were found by Schreiner to be represented in the Chippewas soil collected from all parts of the United States and subjected to rigid test.

The exact origin of such material is problematical. Forest soil peats, fire, wildfires, soil oxidation, and lignification might be mentioned. Of a certainty, the species of distribution are the natural lines suggested by physical weathering. This carbonized material is important, as it makes up an inconsiderable part of the soil humus. It is very constant, and consequently lends stability to the soil organic matter. It can be divided into two general groups, organized and unorganized; in the former the original structure remains intact, while in the latter the original features have been obliterated. The study of such material and the changes that it undergoes not only increases the list of known organic compounds existing in the soil, but throws considerable light on the nature of the soil organic matter as a whole.

36. The estimation of the soil organic matter. —

Many methods have been proposed for the determination

¹ Schreiner, O., and Brown, S. R. Occurrence and Nature of Carbonized Material in Soils. U. S. D. A., Bur. Soils, Bul. No. 3012.

of the organic matter is safe, but some have proved entirely satisfactory, since the composition of this material is so complicated and so likely to change with under investigation. Other soil constituents also tend to interfere with the determination. The general methods seem worthy of mention, as they have been used very widely as soil analyses and at least give comparative, if not absolutely accurate, results.

*Loss on ignition.*¹ This is a simple method which changes to form all the organic matter and determines its loss by difference. Five grams of dry soil are placed in a platinum dish and ignited at a low red heat until the organic matter is all oxidized. The cold mass is weighed with maximum care and the soil heated to a temperature of 1207°C. in order to expel the excess of moisture. The loss is noted as organic matter.

This method is open to the objection that, besides the loss of organic matter, a certain small amount of water of constitution, together with all ammoniacal compounds, alcohols, all carbon dioxide, and some alkali chlorides if the temperature is raised too high, is driven off. The method therefore gives high results, especially in the presence of large amounts of hydrated silicon. An attempt to replace the carbon dioxide is made in the treatment of the cold mass with ammonium carbonate. Notwithstanding these objections, this method is one of the best and is very generally used all over the world in estimating the organic matter of the soil. Very often

¹ Hirston, R. A., and McIntosh, F. W. A Modification of Gaudreau's Method for the Determination of Brown. U. S. D. A., *Tex. Chem., Ind.*, 38, (edited by R. W. Wiley), pp. 26-27, 1924.

the emulsion is carried on in a current of oxygen over hot copper oxide. The organic matter may thus be estimated very accurately, and the organic matter calculated by multiplying the carbon found by the factor 1.754.

Chromic acid method.—This method, proposed by Will, has been modified and improved by various chemists. Warington and Paine² have perhaps done more with the method than any other investigators. In the United States the modification of Cameron and Brewster³ has been very generally accepted. It consists in the treatment of the soil sample with sulfuric acid and chromic acid or potassium dichromate. The organic matter in the presence of the sulfuric acid and oxidizing agent, evolves carbon dioxide until, if the mixture is boiled, practically all of the carbon in the soil drives off. The gas is drawn through a train of absorption bulbs, which is a solution of potassium hydroxide and then weighed. On the supposition that organic matter is 18 per cent carbon, it is very easy to make the calculation. The carbon found may be multiplied by 1.754, or the number directly by 4.71. The product is considered as all organic matter. The results thus obtained are usually lower than with combustion or ignition methods.

¹For description of methods, see Will, H. F., *Principles and Practice of Agricultural Analysis*, Vol. 1, pp. 363-367. Boston, Pa., 1906.

²Warington, B., and Paine, W. A. On the Determination of Carbon in Soils. *Proc. Chem. Soc. (London)* Trans., Vol. 27, pp. 397-400, 1880.

³Briggs, A. J., and others. The Chromic Acid Method of Volatilizing Soil Nitrogen. U. S. D. A. *Proc. Bul.* Bul. 20, pp. 41-52, 1904. Also, Cameron, T. K., and Brewster, J. P. The Organic Matter in Soils and Subsoils. *Ann. Amer. Chem. Soc.*, Vol. 26, pp. 20-45, 1904.

due to the resistance to oxidation¹ by the carbonized matter already dissolved. This material, while it no longer is ignitable, resists the action of the sulfuric and chromic acids to a very large degree.

10. The estimation of soil losses.—The common method of losses estimation is that proposed by Grassi.² The sample of soil is first washed with acid in order to remove all bases. It is next treated with ammonia, which will then dissolve out the humus materials. By catching this peroxide, evaporating it to dryness, and weighing it, the percentage of losses may be calculated. The dark humous extract obtained with the ammonia is called the Maclure Nitric.

This method has undergone several modifications³ of which that of Hilgard⁴ and that of Horton and McBride⁵ were the most promising. The method of the latter chemists has been adopted by the Association of Official Agricultural Chemists and is considered as the official method. In the procedure an attempt is made to keep the concentration of the ammonia in contact with the soil constant during the extraction. Consequently the sample after treatment with the acid is washed into a

¹ Kricheldorf, U., and Steyer, R. B., *Composition and Nature of Carbonized Material*, in *Soils*, H. S. D. L., Dec. 1906, Vol. 36, 101, 10-11, 1907.

² Grassi, L., *Trattato d'Analisi de Miniere agricole*, I, p. 334, 1897.

³ A comparison of the various methods is found in Hilgard: *Alloys*, P. J., and others, *The Determination of Humus*, *Min. Agr. Eng. Soc.*, Vol. 115, June, 1913.

⁴ Hilgard, S. W., *Humus Determination in Soils*, U. S. G. S., *Proc. Assoc.*, Vol. 20 (quoted by U. W. Wiley), p. 80, 1904.

⁵ Hilgard, S. W., *Official and Provisional Methods of Analysis*, U. S. D. A., *Dir. Chem.*, Vol. 237, p. 13, 1905.

90) calc. carbonate free, which is fitted to the mark with 4 per cent ammonia. Digestion is allowed to proceed for twenty-four hours, with frequent shaking, and not so slight portions of the supersaturated liquid is taken for analysis. This method with its modifications is probably the only one that we have for the estimation of soil humus. It is based on the fact that when a soil is heating in active basic material, the humus substance is converted with ammonia. A modification of this method may be used as a test for soil acidity, as any soil of humid regions allowing the extraction of humus by ammonia also must lack basic material.

The composition of the ash extractability of the material is given by Saylor* as follows, the data being the average of eight analyses:—

THE AVERAGE COMPOSITION OF MINNESOTA PRAIRIE SOILS

| | Percentage |
|--|------------|
| Insoluble | 65.01 |
| FeO | 2.12 |
| Al ₂ O ₃ | 7.48 |
| SiO ₂ | 2.30 |
| MnO | 8.12 |
| CaO | .10 |
| MgO | .26 |
| P ₂ O ₅ | 12.27 |
| SO ₃ | .38 |
| Cl ₂ | 1.64 |

The relatively high percentage of phosphoric acid is immediately noticeable in this analysis. This indicates

*Saylor, *Comp. Soil. Minnesota Agr. Exp. Sta., Bul. 11, p. 33, 1906.*

that no mean portion of the soil phosphorus is held in organic combination. The provision of favorable factors does not mean that there is a considerable amount of phosphorus for plant utilization.

39. Organic content of representative soils. — The organic content of soils varies widely according to climatic conditions. The following average data show the limits of variation as well as the comparative content of the important soil sections of the United States:—

ORGANIC CONTENT OF VARIOUS SOIL SECTIONS

| | Percentages | | Other factors and factors | |
|--------------------------------|-------------|----------|---------------------------|----------|
| | Soil | Moisture | Soil | Moisture |
| North Central States | 4.84 | .70 | 5.90 | 1.07 |
| Northeastern States | 4.06 | .80 | 3.70 | 1.35 |
| South Central States | 1.10 | .35 | 1.80 | .45 |
| Southwestern States | .90 | .45 | 1.05 | .25 |
| Mountain States | .59 | .35 | 2.04 | 1.11 |
| Arctic States | .39 | .35 | 1.55 | .32 |

It is at once apparent that the subsoil contains considerably less organic matter than do the surface layers. Also, the areas of the United States that have been glaciated are relatively richer in organic material than the residual, coastal plain, and arid regions. This is largely a climatic and geobotanical relationship. Some soils, particularly alluvial soils, very often run higher than the average data given above. An organic content of 5 or 6 per cent is not an uncommon figure with such materials. Muck and peat soils are of course not to be classified with the above, as their organic content may

range from 35 to 85 per cent, according to the abundance of mineral matter from extraneous sources.

36. The humus content of soils. — The humus content of soils is of course lower than the organic matter therein contained. It therefore varies according to climate and region, not only in amount, but also in composition. The following data, compiled from Hilgard's¹ illustrative table, give:

THE HUMUS OF SOILS AND DECOMPOSITION

| | Humus in Soil (Percentage) | Humus in Soil as Decomposed (Percentage) | Humus in Soil as Decomposed (Percentage) |
|------------------------------------|-------------------------------|---|---|
| 1. Acid volcanic soils | 50 | 15.50 | .175 |
| 2. Volcanic and alluvial | 1.00 | 0.50 | .005 |
| 3. Alluvial soils | 5.00 | 0.50 | .005 |

It is evident that humid soils not only contain the greatest amounts of organic matter, but also exert the greatest influence on the soil. The humus of the soil, however, is not only nitrogenous, but also contains a great amount of water-soluble nitrogen, due to the presence of decomposition products. As a consequence the nitrogen in the soil of humid regions is not greatly in excess of that in the soils of arid climates.

The percentage of humus not only decreases to the lower depths of soil, but also changes in composition, becoming poorer in nitrogen the deeper the soil is penetrated. The following data, as a further illustration, quoted by Hilgard² may be cited as an example:

¹Hilgard, G. W. *Soils*, pp. 128-131. New York, 1901.
²Ibid., p. 128.

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THE EFFECT OF A THERMAL GRADIENT, ETC.

| Depth in Feet | Temperature of Water | Percentage of Increase in Depth | Percentage of Increase in Density |
|---------------|----------------------|---------------------------------|-----------------------------------|
| 1 | 1.25 | 5.50 | .054 |
| 2 | 1.15 | 4.50 | .054 |
| 3 | 1.14 | 3.45 | .054 |
| 4 | 1.17 | 2.70 | .041 |
| 5 | .91 | 2.15 | .015 |
| 6 | .85 | 2.00 | .016 |
| 7 | .87 | 2.55 | .015 |
| 8 | .78 | 1.55 | .015 |
| 9 | .74 | 2.55 | .015 |
| 10 | .73 | 1.15 | .006 |
| 11 | .63 | 1.55 | .005 |
| 12 | .64 | 1.80 | .006 |

Other depth relationships, especially regarding the proportions of water, bottom, and water, are brought out in the following data, obtained by Henry and Hall in the study of the water table:

COMPARISON OF A WATER COLUMN, MEANING, ETC., AND GRADES

| Depth in Feet | Temperature of Water | Temperature of Air | Percentage of Increase in Depth | Percentage of Increase in Density | Ratio of |
|---------------|----------------------|--------------------|---------------------------------|-----------------------------------|----------|
| | | | | | W |
| | | | | | W |
| | | | | | W |
| 1 | 5.81 | 7.47 | 1.50 | 1.00 | .57 |
| 2 | 1.05 | .85 | 1.00 | .80 | .89 |
| 3 | .86 | .71 | .40 | .55 | 1.2 |
| 4 | .85 | .74 | .30 | .60 | 1.7 |
| 5 | .854 | .77 | .18 | .80 | 5.6 |
| 6 | .857 | .74 | .18 | .85 | 5.9 |

Henry, F. J., and Hall, C. R. The Water Table of Virginia, Carolina, and Florida in the Atlantic States. *Memoria Ag. Rep. Ser.*, 1913, Ann. Rep., p. 105. 1917.

300. Influence of the original material on the resultant humus.—It is evident that the source from which any humus material is derived will exert a profound influence on its composition, especially its nitrogen content. Snyder¹ has investigated this by making certain materials rot a year prior to humus and allowing the process of decay to proceed for a year under favorable conditions. At the end of the period the humus was extracted by the Gifford's method. The results are given below:

PER CENTAGES OF HUMUS EXTRACTED FROM VARIOUS ORIGIN MATERIALS

| | C | N | O | H |
|------------------------|-------|------|-------|------|
| Sugar | 57.04 | 3.04 | 20.04 | .59 |
| Barley | 40.98 | 3.23 | 42.07 | .35 |
| Grain straw | 54.00 | 2.95 | 43.75 | 2.30 |
| Wheat straw | 51.02 | 3.82 | 40.14 | 1.02 |
| Corn leaves | 41.03 | 6.20 | 43.02 | 0.81 |
| Grass leaves | 54.32 | 2.45 | 24.16 | 1.28 |
| Wheat hay | 48.77 | 4.30 | 38.07 | 0.38 |

Although the humification may not have reached completion in this case, the great variation in nitrogen is striking. Starting, as it probably does, nearly as well under and somewhat alike, it will change readily to various and exert a marked effect on plant growth. Finally the variation of the nitrogen in soil humus is the most potent factor in the nutritive flourishing of the material. The variability of the carbon, hydrogen, and oxygen of the soil humus is not such an important factor, as these elements can easily be supplied to the

¹Snyder, Harry, Production of Humus from Manure. Minnesota Agr. Exp. Sta. Bul. 24, p. 26, 1897.

soil by the plowing under of green materials or of hay, yard manure. In general, the percentage content of organic matter increases as the organic matter decays.

III. *Effects of organic matter on soil.* — The effects of the organic matter on soil and plant conditions are as numerous as they are complex. Some of the influences are direct, others are indirect. As the specific gravity of organic matter is low, the first effect of its addition would be to lower the absolute and the apparent specific gravity of the soil. As the water capacity of humus is very high, a soil rich in organic constituents would possess a high water-holding power. This water possible gains volume changes both on drying and in the presence of excessive moisture. The granulating effects of settling and drying and freezing and thawing are likewise accelerated. The organic matter tends also to spread the individual particles of soil further apart, especially in a clay. Its loosening effects are immediately apparent in such soil. On the other hand, because organic matter has a higher cohesive and adhesive power than sand, it performs the function of a binding material with the later soil, a condition much to be desired in a material possessing such textural characteristics.

The better tilth induced by the presence of organic matter in any soil tends to facilitate ease in draining and to encourage good aeration. These two reactions are of course necessary for the preservation of soil aeration. Root extension and bacterial activity are thus increased. It is of especial importance that the splitting up of the organic matter shall take place in the presence of plenty of oxygen, in order that toxic compounds may not be produced and that a humus highly favorable to plant growth shall be produced. The increased value

capacity of the soil resulting from the presence of organic materials is of some importance in draught resistance, while the block value imparted by the humus tends to ease the electrolytic power of the soil for heat.

The soil organic matter, however, functions in other ways than those already sketched. The humus in its degradation products may serve as plant-food. Bacteria and other soil organisms are also furnished a source of energy thereby, and the production of carbon dioxide is much increased. This carbon dioxide, as well as the organic acids generated, tends to raise the capacity of faecal matter as a solvent agent, and thus the amount of mineral plant food available to the crop is greatly increased. The general effect of organic matter, then, is to better the soil as a foodhold for plants, and to remove either directly or indirectly the available food supply for decay.

226. *Maintenance of soil organic matter.*—The maintenance of a proper supply of organic matter in a soil is a question of great practical importance, as productivity is governed very largely by the humus content of the soil. This maintenance of the soil humus depends on two factors—the source of supply and methods of addition, and the protection of proper soil conditions in order that the organic matter may perform its legitimate functions.

The organic matter of the soil may be increased in a natural way by the growing and use of green crops. This is natural green-manuring and is a very satisfactory practice. Such crops as rye, buckwheat, clover, peas, beans, and vetch lend themselves to this method of soil improvement. Not only do these crops increase the actual carbonaceous content of a soil, but in the case of legumes the nitrogen also is increased in amount, due to the

antibiotic action of the nodule bacteria. Green-manure crops may also protect the soil from loss of plant food by leaching. The addition of harrowed manure is a common method of raising the organic content from vegetable sources, and in changing this manure performs the same function as natural soil humus. Nitrol, peat, straw, or leaves may be used in a similar manner.

Improper soil conditions not only prevent the proper decay of organic matter, but also tend to encourage the production of products harmful to plant growth. Therefore, to make that organic material added to any soil may produce the proper humus conditions and perform their normal functions, soil conditions in general must be of the best. The drainage should be installed, if necessary, in order to promote aeration and granulation. Lime should be added if basic materials are lacking, for it promotes bacterial activity as well as plant growth. The addition of fertilizers will often be a benefit, as will also the establishment of a suitable rotation. The rotation of crops not only prevents the accumulation of toxic materials, but also, by increasing crop growth, makes possible a larger addition of organic matter by green-manuring.

Good soil management tends to adjust the addition of organic matter, the soil conditions, and the losses through cropping and leaching, in such a way that perfect crops may be harvested without impairing the human supply of the soil. Any system of agriculture that tends to permanently lower the organic matter of the soil is impractical, and unprofitable, as well as undesirable.

THE GLOBAL MATING RITUAL

Three of the following general references may prove of use:

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colloidal material does not differ from crystalline in chemical composition, but the distinction is merely one of size of particles. For example, if large particles are suspended in water, they will immediately sink, since their weight is so much greater than the surface that is exposed to buoyancy. When these particles are decreased in size, their weight decreases much faster than the surface exposed. It is therefore evident that a point will at last be reached at which the particles, because of their minute size, will form a homogeneous solution. The upper limit of the colloidal state has then been reached.

100. The colloidal state. — The colloidal state in which these particles are now found is a peculiar one, and resembles much closely not only in properties, but also in the size of particles in which the material exists. The upper limit of the size group so designated by the above fraction of the United States Bureau of Standards is .006 millimeter, while the upper limit of the particle existing in a colloidal state is estimated to be below .006 of a micron, or .00006 millimeter. Indeed, so small are the colloidal particles that they become molecular complexes, that is, a few molecules may go to make up a particle. The various colloids, or the same colloid under different conditions, may exhibit greatly differing sizes of particles. Some colloidal particles are very large, approaching the upper limit already set for material in such a state. Other particles are finer. It is evident that a predilection must exist until a particle is reached which consists of only one molecule. The solution then ceases to be a molecular complex and becomes a true solution. The colloidal state thus grades into the true solution, just as ordinary suspensions grade into a true, or colloidal

regions. While this method of comparison fails to recognize the various planes that colloidal materials may exhibit and is therefore faulty in this regard, it does lay emphasis on the differences as to size of particles that exist between colloidal bodies and materials as they are ordinarily recognized. The relationship is shown by the following diagram:—

ORDINARY PARTICLES | COLLOIDAL STATE | X-RAY REGION
RELATIVE SIZES

Fig. 22.—Diagram showing the relationship of the colloidal state (intermediate region) to ordinary particles and to x-ray diffraction.

Since colloidal particles vary in size from .005 of a micron to a micron, the range must be very great. Just how great cannot be very accurately stated. It is interesting to note, however, that this range is much greater in proportion than is existing between the size provided the ordinary clay particles found in soil. With this possible difference, it is no great wonder that the various colloids exhibit with different intensities the characteristics as particles in films and of such great importance in everyday life. The particles in the upper range of the colloidal field can be seen with the ordinary microscope. As such particles become smaller they cease to be visible under the ordinary microscope and can be detected only by the ultramicroscope. It is probably true that by far the greater proportion of the particles of material in a colloidal state cannot be detected by microscope means. This prediction of colloidal materials and the extreme fineness of the particles is well illustrated by the following diagram (Fig. 23), although it fails to convey any idea regarding the various planes that collectively occupy



FIG. 21.—Diagram showing the possible range in the size of colloidal particles.

304. The properties of colloids.—In general there are certain properties which materials in a colloidal state exhibit and by which they are distinguished from true solutions. In the first place, since they are not in true solution they exert little effect on the freezing point, on vapor tension, and on vapor pressure. Some colloids have absolutely no effect on these conditions, while others as they solve a certain small amount of true solution to take place, do possess such

influence to a slight degree. Secondly, colloids do not pass readily through semipermeable membranes, as parchment paper, while crystalline do. This serves as a very easy way of separating colloidal and crystalline material. As a matter of fact, the membrane is itself a colloid. Thirdly, heat and the addition of electrolytes will serve to coagulate or precipitate certain colloids, a property which again serves to distinguish them sharply from a true solution. Fourthly, colloidal material has great absorptive power, not only for water, but also for materials in solution, a quality of extreme importance in soil studies.

It has been shown that a colloid is a material in a certain state of division, in which it exhibits properties not possessed by an ordinary compound or by a true solution. It is therefore proper to speak of matter as divided as being in the colloidal state or colloidal condition. It is not to be inferred, however, that the colloidal phase is equivalent with the crystalline, that colloids are compounds. They may or may not be so, such a condition, however, the same material may exist without chemical change either in the colloidal or non-colloidal state. For example, silicic acid, ferric hydrate, gold, carbon black, and other materials may or may not be colloidal, according to circumstances. The freedom of division is the explanation of colloidal properties. In order to place such a discussion on a more understandable basis, a few illustrations of the colloidal state will not be amiss. The following materials which may exist as colloids may be far more conveniently grouped under the general heads, organic and inorganic:—

Organic: Gelatin, agar, casein, albumin, starch, jelly, honey, carbon black, animal soil, etc.

Isomeric: Gold, silver, iron, ferroc hybridized, scattering solids, zinc oxide, silver iodide, Prussian blue, etc.

III. Colloidal phases.—In general, two conditions are necessary for the colloidal state: a disperse medium, and a material that will disperse, the latter being usually designated as the disperse phase. Three systems may function as a disperse medium—a liquid, a solid, or a gas. In these same ways, with each disperse medium there may be three disperse phases—a liquid, a solid, or a gas. This gives us general phases to be considered in colloidal chemistry. From the well-studied case, the lyophobic and the liquid-liquid phases are by far the most important and will be the only ones to receive detailed attention here. In the liquid-liquid phases as with colloidal gold or ferric hydrate, the particles are suspended in water as the disperse medium. In the case of gels, another liquid-liquid example, the jelly surrounds the disperse medium, or liquid. An emulsion may exhibit the liquid-liquid phase, and possibly mixtures with rich in lipids.

In these colloidal phases under discussion and of such particular interest in soil study, two general classes of materials are found, which seem to differ radically from each other and yet are likely to lead to considerable confusion unless special pains are taken to distinguish between them. An organo-gelatin and a colloidal suspension of ferric hydrate may be cited. The gelatin is considerably more viscous than water, while the ferric hydrate does not differ from water in this respect. The former gelatin does not coagulate on loss of moisture, but will become dispersed again on its addition or presence of water. In other words, it will pass again and again, back and forth

iron sand to a gel. It is what might be called a *reversible colloid*. Moreover, it is not coagulated by ordinary addition of salt or by heating. The ferric hydroxide colloid, on the other hand, when precipitated or agglutinated by any means may not easily be brought back again to the original state. It is an *irreversible colloid*. Moreover, it is thrown down by the addition of electrolytes. These colloid, then, the recent, gelatinous, reversible colloids and the non-reversible, non-gelatinizing, easily coagulable, and non-reversible colloids, besides all gradations and variations between the two. In the ordinary clay soil, both types of these materials probably exist and play important parts in the physical and chemical characteristics exhibited.

125. *Flotation.*—While the gelatinous colloids of the soil, such as some of the basic materials, are not agglutinated by the addition of electrolytes, most of the colloids of a nature similar to colloidal silicic acid and ferric hydroxide thrown down by heat treatment. This phenomenon is often spoken of as *flotation*. A very good example is afforded by treating a clay suspension with a little caustic lime. The tiny particles almost immediately coalesce into floccules and, because of their combined weight, sink to the bottom of the containing vessel, leaving the supernatant liquid clear. The same action will take place in the soil itself, but of course with less rapidly and under conditions less accessible to the eye. The colloids thus thrown down, being largely *irreversible*, cannot again assume their former identities and thus lose their distinguishing characteristics. In general, while being about description while silicates do not, calcium oxide and calcium hydroxide being the best-known exceptions to the latter. *Appendix B* contains references.

But for the phenomena of flocculation or agglutination may be accounted for theoretically it is rather difficult to state. The general theory is one of electrification. It is found that certain colloids, when subjected to the proper electric current, will separate to either the positive (anode) or the negative (cathode) pole. These particles evidently carry a charge of electricity. Potassium ferriate, aluminum hydroxide, and hair dyes, for example, were stated the colloid and carry a positive charge; while ammonia, alkalis, alkali soaps, gold, silver, and wool dyes were termed the acids and are negative. It is assumed that as long as the colloidal particles remain charged they repel each other and the colloidal state persists. When an electrolyte is added the ionization is supposed to cause a discharge of the repelling electricity neutral by the colloidal particles, and flocculation or agglutination immediately takes place.

Certain colloids may flocculate certain others, as the gelatinization of siliceous soil by ferric hydroxide. At times one colloid may precipitate another, probably by coagulation, it with a precipitate like. Such a case may be shown by adding gelatin to a clay suspension. When a colloid such as ferric hydroxide is flocculated, it loses to a certain extent its peculiar properties, and assumes the characteristics of ordinary materials. It is evident, therefore, that if the properties exhibited by colloidal materials become either directly or indirectly detrimental to plants, their flocculation would be beneficial. In fact, provided this is usually accomplished by the addition of lime. The colloidal material existing in a normal soil and possessing a gelatinous nature, similar to gelatin, is probably not all flocculated by the addition of ordinary amounts of electrolytes. This material may be influenced by

lysis, whereby it slowly gives off water, becomes more and more viscous, and at last may lose its gel qualities and become hard and irreversible. It is evident, therefore, that wetting and drying, frost, and the like, become factors in dealing with this form of colloidal matter.

(11) Common soil colloids and their generation.—The common soil colloids may, for convenience, be discussed under two broad, organic and inorganic. Of the former, the so-called humic acid stands as the exemplar; of the latter, silicic acid, ferric hydroxide, and mucopolysaccharide aluminas are the counterparts.

Organic colloid.—The humic colloid is a natural body and probably made up of the bulk of the colloidal matter. Such material is very heterogeneous, very complex, and constantly changing. As yet very little study of the organic soil colloid has been made because of the difficulties presented by the problem. Humic colloid may be viscous or non-viscous, as the case may be; and may or may not be thrown down by acids. The adsorptive power of these colloids for water, gases, and such materials as sodium, magnesium, and potash, is

*Van Dorsselaer, F. M. *Die Absorption*. Seite 116-118. Dresden, 1914. Also, *Die Adsorptionsverhältnisse und die Hauptbestandteile der Kolloide*. Leipzig, 1916. Seite 146, Seite 151-152, 1918.

May, J. F. On Deposition of Salts or Crystalline Matter in the Lower Beds of the Chalk Formation. *Trans. Chem. Soc.*, Vol. 6, pp. 125-136, 1854.

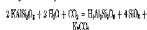
Warington, E. On the Facts Taken by Smith of Iron and Manganese in the Adsorption Action of Silica. *Ann. Chem. Phys.*, 2d ser., Vol. 6, pp. 1-33, 1858.

Orderson, A. R. The Colloid Theory of Plastering. *Trans. Amer. Cer. Soc.*, Vol. 6, pp. 45-70, 1903.

Vilberg, H. S. The Colloid Nature of Clay and Its Mineralization. *U. S. Geol. Sur.*, Bul. 185, 1908.

very highly developed—more so, probably, than that of the inorganic colloids. These organic colloids are formed during the huming-down and splitting-off processes of bacterial activity. Some of the basic materials are those of it is a sufficiently fine state of division to assume the condition that has been designated as colloidal. Of course the chemical *history* of weathering is also operative in this process of organic colloidal production.

Altered colloids. The inorganic soil colloids, especially ferric oxide and silicic acid, are less complex than the organic and have been more thoroughly studied. Such colloids are generated during the operation of the ordinary forces of weathering, especially the chemical phase. For example, when a feldspar undergoes decomposition, the following reaction may be used to illustrate the possible change that takes place:—



Kaolin practically always has its origin in this way, together with an silicic carbonaceous silica. The process is essentially one of hydrolysis and colloidization; the CO₂ by reacting with the alkali permits the process to go on. The silica may go in three directions, according to conditions— to free silica, to hydrated silicates, and to colloidal silica. Similar reactions may be written for iron and aluminum, but they can only show, as does the above, the general trend of the change. In general it can be concluded that most inorganic colloids arise from ordinary chemical weathering, together with secondary minerals of various kinds. Such colloids must be very dense and are difficult to study because of their reaction among themselves.

108. *Preparation of colloids.*—There are a number of methods that may be used in the preparation of artificial colloidal solutions, but the description of only one will suffice in the present discussion. This is the use of a soapemulsion membrane. It has already been mentioned that crystalline powders pass through a membrane such as parchment paper, while colloids do not. It is reasonable to expect, then, that these materials may be thus separated by proper adjustments. As a matter of fact, such a procedure is employed in many cases. The operation is called dialysis, and the membrane, itself a colloid, is designated as the dialyzing membrane.

For example, if a solution of ferric chloride in which some potassium carbonate has been added is placed in a dialyzer with pure water on the outside, the hydrochloric acid and other impurities gradually pass through the membrane and a more or less pure colloidal solution of ferric hydrate is left behind. The alkalies in this method live in its extreme degree. Nevertheless, since the cells of plants present a comparatively nonporous, dissolving of preparation serves to explain many actions that go on between soil and plant during the process of nutrition. In this soil the formation of colloidal material is entirely a natural function of chemical and biological forces under such conditions that the particles split off from that natural division which has been designated as colloidal.

It may be inferred that the quantity of colloidal matter in an average soil is large; but, as a matter of fact this is not the case. The proportion of the soil in a colloidal state at any one time is very small. It must be remembered, however, that material is continually being thrown out of the colloidal condition and at the same time more

is permitted; thus the effects may be masked, although the amount present at any one time is extremely minute.

1.69 Cohesion and soil properties.—As may naturally be inferred, the influence of the colloidal matter on soil conditions, especially as related to plants, is extremely important. This influence is exerted in two ways. First, on cohesion and plasticity; and, secondly, on the solvent (free) power of the soil. Both these qualities must be considered, not only in the physical, but also in the chemical and the biological study of the soil as a medium for crop production.

In general it is found that, other conditions being equal, as increase of colloidal matter increases plasticity; in other words, the ease with which a soil may be worked into a profitable condition becomes greater. This is a rather undesirable quality when too pronounced, and in crops in which it is most likely to be developed some means of checking this colloidal influence is advisable. The great plasticity is developed because the colloids, especially those of a gelatinous or viscous nature, facilitate the ease with which the particles may move over one another and get caked sufficiently to prevent tilthness of the mass. In general, also, the greater the plasticity of a soil, the greater is the cohesion when dry. In soils, then, in which the colloidal material is very high, chaffing may occur if the soil is tilled too dry because of the great tendency of the particles to cohere. The cohesion and plasticity, as factors in soil structure, soil penetration and tilth, will be discussed in the succeeding chapter. It is sufficient at this point only to observe the relationship of colloidal material to the development of soil qualities.

The second important attribute imparted to soil by

colloid development is high absorptive power. This power extends not only to condensation of gases, but also to water and to materials in solution. The water of condensation on clay and particles when exposed to a saturated atmosphere is largely determined by the colloidal content. In other words, the surface exposure of colloidal matter is so perpetuated in water condensation as in a general way to allow the one to be a relative measure of the other. Again, colloids exert absorptive power for material existing in the soil water, and to a limited extent compete with the plant for food. Until the colloids are neutralized the soil solution may not reach its maximum effectiveness for crop growth. This absorptive power is exerted especially on the basic materials, such as carbonates, and when the existing colloids are fully neutralized the soil tends to become lacking in available bases. This reaction is generally termed soil acidity. It may readily be seen that the concentration of the soil solution is governed to a considerable extent by the colloidal content of the soil, and that the adjustments in concentration are always toward an equilibrium between the two. Colloidal matter does not exert the same absorptive power for all materials, but is capable of what might be called selective absorption. For example, if ammonium sulfate is added to a soil, the ammonia is strongly taken up, which tends to reduce the sulfate. The continuous use of such a fertilizer on a soil poor in lime will ultimately result in the presence of free sulfate acid. This example is sufficient to emphasize the relationship of absorptive power to fertility practice.

116. Factors affecting cationic — It must not be inferred from the foregoing discussion that the presence of anions is detrimental to soil conditions. In light

make the presence of such material is extremely necessary, as it tends to bind the soil together, facilitates granulation, and prevents loss of plant food by leaching. It is only in heavy soils in which such material is excessive that a detrimental condition is likely to exist. This occurs because of a high viscosity and plasticity, because of the competition for food that is likely to arise with the crop, and because of the hindrance to root activity. Where lime is free or lacking, the situation has a tendency to become still more aggravated by further colloidal development.

In general, the practice of subsoilings by allowing the setting and drying of the soil is probably in the final stage not only for the raising of excessive and improper colloidal influence, but also for the encouragement of just the right development thereof. The timing of winter, depth at proper times, the addition of boron, and the application of lime are all practices that aid in the control of colloidal existence. Since this control and utilization of colloidal influence is only a phase of soil structure as related to tilth and granulation, a further discussion of the subject will be reserved for later consideration.

III. *Retention of colloidal content.* The colloids in the soil are so complex, so numerous, so variable in function, and so susceptible to change, that an exact determination of their amount is impossible. The knowledge of colloidal material in general is so meager that it is not surprising that such slight advances have been made in fully and clearly determining their character as a colloidal material, or the soil unavailability is. The important methods of estimating the colloidal content of the soil depend for their expression on the intensity of

certain qualities, supposed to be developed largely by colloid content. This indicates that the methods are largely comparative, rather than exact or strictly analytical in nature. These important methods¹ are three in number: Van Buren's, Ashby's, and Wineland's.

Van Buren's.—The first investigator to advance a method for colloid estimation was Van Buren,² who considered that the amount of silica dissolved from a soil by digestion with hydrochloric or sulfuric acids was a measure of its colloidal content. It is now known that some materials, such as crushed rock, may yield as much silica with this treatment as a highly colloidal clay. This method is not of great importance at the present time, except as to the information that it gives regarding the evolution of colloidal soil study.

Ashby.—A second method, and one of much more value, has been evolved by Ashby.³ He found that the absorption of uranic dye by soils afforded a very good index to colloidal content. The difficulty in this method, however, has in choosing the most effective dye and adjusting its concentration. Moreover, different soils which may be much in absorptive capacity for the same dye, but only slightly expansive, would have time for loss

possible.

Wineland's.—The third, and as yet the most value-

¹A comparison of these methods is found in Adams, Brown, H., and Jorris, R. *The Understanding in Colloidal Chemistry: Effects in Soil Science*. University of California Publications, Berkeley, 1916.

²Van Buren, J. M. *The Adsorption of Uranic Dye by Soils*. Ph.D. thesis, University of California, Berkeley, 1911.

³Ashby, E. R. *The Colloid Science of Clay and Its Measurement*. U. S. Soil Ser., Bull. 228, 1918.

able mode of coloidal estimation is that of Mitscherlich,¹ in which the absorptive capacity of the soil is again made the comparative index. Water instead of dye is used as the absorbent material. In this method the air-dry soil in a thin layer is brought to absolute dryness over phosphorus pentoxide. It is then placed in a desiccator over a 10 per cent solution of sulfuric acid and the reabsorption is limited by a partial vacuum. The sulfuric acid is used in order to prevent the deposition of dye on the soil. After exposure for at least twenty-four hours the soils are found to have taken up their maximum residues of non-aqueous, which is called the hygroscopic index. The soil is then weighed, and the increase, figured to a percentage basis, is taken as a measure of coloidal material. The reverse process is very also followed, by exposing the dry soil in a saturated atmosphere and allowing it to dry over phosphorus pentoxide. The hygroscopicity of the soil, or its hygroscopic coefficient, is thus the basis for coloidal estimation. It is now clear why the term coloidal estimation is employed in this discussion, rather than coloidal determination.

An objection to the Mitscherlich method is advanced by Ehrenberg and Vick,² who claim that the drying out

¹ Kretsch, H. and Mitscherlich, A. K. Die Bestimmung der Pflanzennährstoffe. Landw. Vers. Stat., Band 21, 1864-65, 441-1968; also, Mitscherlich, H. A., and Floss, H. Die Bedeutung der Bestimmung der Hygroscopicität und der hygroscopischen Koeffizienten. Landw. Vers. Stat., Band 21, 1864-65, 441-1968.

² Ehrenberg, P. and Vick, H. Beiträge zur physikalischen Bodenuntersuchung. Teil I. Feuchte und Aggregaten, Band 45, Seite 25-27, 1913; also, Ehrenberg, P. Die physikalische Mitscherlich'sche Theorie der Hygroscopicität von Bedeutung der Gekochtheorie und der Wert zur Beurteilung der Hygroscopicität. Landw. Vers. Stat., Band 45, Seite 77-80, 1913.

phenomena possible will complicate certain results and lower their absorptive power, thus causing the hypomeric coefficient to become an unreliable comparative figure. They suggest first the exposure of the foil and over the water and sulfuric acid, and then the extraction of the hypomeric water over phosphoric acid. Since this modification is very slow, the original Blomberg method, in spite of its faults, remains the most valuable up to the present time.

CHAPTER X

SOIL STRUCTURE

When texture is the term used in reference to the size of the particles in a soil mass, the word structure is employed in reference to the arrangement of the grains. The structural condition of the soil is very important to plant growth, since the circulation of air and water are so necessary to normal development. The structural condition may be loose or compact, hard or friable, granulated or non-granulated, as the case may be. Of these conditions, granulation, especially in heavy soils, is of vital importance, since it is really a summation of all favorable structural conditions. By granulation is meant the clumping together of the small particles around a suitable nucleus, so that a crumb structure is produced. The grains thus come to function singly. The importance of such a structural condition on a heavy soil is very obvious. The soil becomes loose because of the larger units, air moves more freely, and water not only drains away readily when in excess, but responds with celerity to the capillary pull of the plant. Hence the promotion of granulation and the factors that function therein may be briefly discussed, however, two properties of particular importance, especially in soils of fine texture, must be considered. These properties are plasticity and cohesion.

121. **Plasticity.**—Any material which allows a change of form without rupture, and which will retain this form

entirely when the pressure is removed, but also whereby, as said to be plastic. Putty with a proper admixture of oil is a very good example of a plastic body. As is well known, the various plastic materials differ in their plasticity. Not only this, but such substances as clay or wax differ not only in plasticity with their respective solvents, their plasticity, and their texture. The great difficulty in the study of plasticity has been in finding a means of calculation allowing an exact numerical representation. The normal of hypersonic water that a soil will hold has been used as an expression of elastic quality, as well as shrinkage on drying, the ability to absorb dyes, acidity, and other characteristics. None of these has proved satisfactory, since one quality of a clay or other soil is used as a measure of another quality.

Atterberg¹ has suggested that the difference in moisture content of a clay at the point at which it ceases to be plastic, as compared with the moisture content at which it becomes viscous, might be used as an expression of plasticity. He has called this figure the plasticity coefficient. Thus, a soil may cease to be plastic at 20 per cent of moisture and may flow at 30 per cent. The plasticity coefficient would then be 10. While this is one of the latest methods, it is open to the objection already stated— that one quality of a soil is used as a measure of another. The only showing the same plasticity coefficient by this method may exhibit substantial differences in actual plasticity. Atterberg's testing several methods of representing liquid limit² is no better than when

¹Atterberg, A. Die Plastizität der Fein. Anorgan. Stoffe, *Technische Physik*, 1926, 1, Seite 19-45. 1911.

²Skinner, C. R. A Study of the Atterberg Plasticity Method. *Trans. Amer. Soc. Civil Engrs.*, Vol. 31, pp. 1725-1811. 1916.

already in use. The all practical purposes in will its various, general descriptive terms may be employed.

111. **The cause of plasticity**—Exactly what may be the cause of plasticity has long been under discussion. The various theories advanced may be grouped under the following heads:¹—

A. Structure of clay particles

1. Fineness of grains
2. Plate structure
3. Interlocking particles
4. Spangulation

B. Presence of hygroscopic moisture

C. Molecular attraction between particles

D. Presence of colloidal matter

(Of these theories accounting for the plasticity of certain bodies, that of colloid content seems the most reasonable.) The presence of gelatinous colloidal matter, with a certain optimum amount of water, seems to facilitate the easy movement of the particles while at the same time exerting sufficient force to prevent the body from splitting apart at the time of movement, or when the pressure is removed or the material dried. Thus, in general, other conditions remaining equal, materials become more plastic the greater the content of colloidal matter. In general the colloidal fraction is a measure of plasticity. The consideration of shrinkage, hygro-

¹ Davis, M. B., *The Plasticity of Clay*, Trans. Amer. Cer. Soc., Vol. LXV, 65-76, 1922.

² Gaudreau, A. S., *The Colloid Theory of Plastics*, Trans. Amer. Cer. Soc., Vol. LXV, 65-76, 1922, 430, 439-440, 447-448.
H. H., *The Colloid Nature of Clay and Its Significance*, U. S. Geol. Survey, Bul. 205, 1920.

capric water, and the absorption as an expression of plasticity becomes logical on this basis.

12. *The importance of plasticity.*—Plasticity assumes considerable importance in a soil when it becomes highly developed, since it governs ease in plowing. The more plastic a soil is, the more likely it is to become puddled by tillage, especially if it has a high moisture content. Thus a clay cannot be plowed wet, since this would allow its particles to be locked into that very plastic condition so detrimental to plant growth. A soil, on the contrary, may be stirred even when saturated, and still its structural condition will not be impaired since its plasticity is low or nil. A very plastic soil is also likely to become exceedingly hard when dry, since its soil granulation, which shows the great care demanded by soils having high plasticity coefficients.

The three factors that affect plasticity to the greatest extent are texture, granulation, and moisture. In general, the finer the texture of the soil, the higher is the maximum plasticity thereof. The more granular a soil, the lower is the plasticity or the tendency to puddle when plowed. The amount of water is the third vital factor. A soil will exhibit its maximum plasticity at a definite moisture content. This point will be somewhere between the firming or viscous condition and the point at which a soil reduces to mud, or, in other words, to become anadry. With a soil such as a clay, in which the plasticity is high, plowing should be done when the moisture coefficient is such that there is no likelihood of puddling, and yet the soil will turn over with a maximum pulverizing effect.

13. *Shrinkage.* Very closely connected with plasticity, but not in exact similarity, is shrinkage. By the

cohesion of a soil is almost the tendency that its particles exhibit in sticking together and in opposing the tensile stress. In general, the greater the plasticity of a soil, the higher is its cohesion, especially when it is dry or only slightly moist. For that reason, cohesion might be made a rough measure of plasticity. Cohesion of a soil varies under two general conditions, the wet and the dry. When a soil attains its cohesion it is developed by the moisture films and the colloidal materials that may be present. This form of cohesion is often spoken of as *tensile*. When a soil loses its cohesion it is developed by some extent by the interlocking of its grains and the deposition of cementing salts. The greatest loss is done up, however, by the drying and shrinking of the gelatinous colloidal matter. As a general rule, the greater the amount of colloidal material, the more firmly the soil is bound together when dry, or, in other words, the greater is its cohesion.

Cohesion is important in tillage operations, in that soils having a high coefficient of cohesion tend to become cloddy when plowed and may thus be rendered poor in physical condition. This may be avoided by timing the operation so that the moisture content is somewhere above the point at which excessive cohesion is exerted. As cohesion is not greatly developed, except in a heavy soil, it is only where fine texture is found that such a danger exists. As already shown, the danger is a double one, for, since high plasticity and high cohesion go together, a soil plowed too wet may puddle while one plowed too dry may clog.

118. *Methods of determining cohesion.*—A number of methods have been devised for determining the cohesion of clays and other soils. One of the earliest was

Stahler's¹ in which was tested the resistance of rectangular prisms of dry soils to penetration by a steel blade. The apparatus consisted of a beam supported on a fulcrum more than one third of the distance from the end. A pan for holding the weights added for causing the crushing was hung at the end of the long arm, while a counterpoise on the short end of the beam acted as a fulcrum. The steel blade was placed at the long end of the arm near the fulcrum. The dry soil prism was placed under the knife and weights were added to the pan until crushing occurred. The weight necessary was designated as the cohesion resistance of that soil.

Holzhumt² measured cohesion by crushing soil cylinders of a definite size. A glass vessel was placed on the top of the column and water was added until the column gave way. The weight necessary to bring this about was designated as the absolute cohesion of the sample. Holzhumt also measured cohesion of soil cylinders of a definite size by determining the resistance to breaking under a transverse load, the soil columns being placed across supports six centimeters apart. On the narrow midway between the ends a steel pan was suspended into which weights were put until breaking occurred. The figure thus obtained was called the relative cohesion.

¹ A good description of Stahler's apparatus is found on page 94 of *Hydrostatics*, by S. A. Mendenhall, published by Paul Thompson, in 1905.

² Holzhumt, H. *Unters. des Zusammenhanges zwischen mechanischen Eigenschaften*. *Forsch. u. d. Gebiete d. Agrik. Physik*, Band 1, Seite 193-207, 1902. Also *Wissenschaftlich Praktische Untersuchungen auf dem Gebiete der Pflanzenernahrung*, Band 1, Seite 72, 1903.

Pachter¹ used a penetration apparatus, consisting of a vertical shaft held by metal guides and counterpoised by a weight hung over a pulley. The shaft was moved at the lower end with a cutting blade, while the upper end carried a scale pan for holding the necessary weights for penetration. The cohesion coefficient was the weight necessary to force the blade a certain distance into the soil. All important apparatus have been modified after either Pachter's or Schödlern's. That of Atterberg's² (see Fig. 34) follows the former, while that of the Bureau of Soils³ (see Fig. 25) resembles the latter.

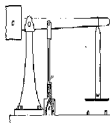


FIG. 25.—Atterberg's apparatus for determining the cohesion of soil. The soil plug is placed between the cutting edge (E) and the shearing plane (F). The weight (C) is added to the counterpoise.

¹Pachter, H. Untersuchungen über die Kohäsionen der Bodensubstanzen. Bericht u. d. Oberw. d. Agr. Physik., Band 12, Seite 185-211. 1908.

²Atterberg, A. The Friction and Cohesion of the Soils. (Internat. Stat. 2. Bodenkunde, Part II, Sect. 2-5, Seite 146-189. 1912.)

³Chapman, F. X., and Collingier, J. H. Minimum Cohesion and Physical Condition of Soils. U. S. D. A., Bureau of Soils, Bul. 60. 1906.

Kennedy & Fisher¹ has found a machine for measuring the crushing strength of dry soil cylinders to be of value in determining the absolute, or maximum, cohesion of soils. The results, as he has already demonstrated, in his previous work, are comparably in relative value at least, to those obtained by simpler methods.

The great difficulty encountered in measuring the natural cohesion of a soil, either wet or dry, is not so

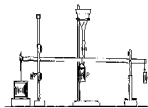


FIG. 25.—The apparatus used by the United States Bureau of Soils for determining the compression of soils. (A) is naturally packed soil, (B) steel piston, (C) steel weight, (D) steel leveling screws.

much in the accuracy of the determination as in controlling physical conditions. The cohesion of a soil depends very much on the handling it has received in the preparation, in the amount of water that is added, and in the amount and length of time of drying. Natural granulation cannot be secured. The Bureau of Soils attempted to overcome these difficulties by mechanical mixing and packing, but the results were abnormal, due to the mixing process. As a consequence, most relative results

¹Johnson, E. *Verfahren zur Untersuchung des des Bodensammens und der Bodenstärke*. *Internat. Mitt. für Bodenkunde*, Band III, Heft 2-3, Seite 141-150, 1911.

have been determined either on samples that have been wetted to a maximum plasticity soil then brought to the required moisture content, or on uniformly compacted samples that have been allowed to take up water by capillarity. In general the curves that would occur with normal gradation, while lower, will follow the direction of a maximum plasticity curve.

III. Factors affecting cohesion. - It is obvious, from what has already been said regarding the general characteristics of soils, that texture must play an important role in the determination of the cohesion factor. In general, the finer the texture, the greater is the cohesion, since, whether the soil is wet or dry, the forces that tend to hold the particles together are stronger than in a coarse soil. The finer the soil, however, the greater is the lateral influence in this regard, due to the very great increase in the binding capacity of the colloidal matter on drying. In a coarse soil this binding effect is small or entirely absent.

Another factor is the granular condition of the samples. In general granulation may be said to be due to an excess of cohesion between a limited number of particles, resulting in a clump, or granule, structure. This granulation, by loosening the soil mass, lowers not only plasticity but cohesion also. The addition of organic matter to a soil, by loosening and increasing granulation, will tend to lower cohesion at every moisture content ranging from a dry to a saturated condition. The following data, taken from Peckham's¹ study of the points just discussed, -

¹ Peckham, H. Untersuchungen über die Zusammenhänge der Plastizität, Festigkeit, u. d. Gleitzeit d. Agg.-Profil, Band 14, Seite 105-211. 1920.

TABLE 1
 RESULTS OF THERMOCHEMICAL, GRAVIMETRIC, AND MOISTURE
 ANALYSES OF SOILS (PERCENT)

| Soil | Percentages in Organic Fraction | | | | |
|---------------------------------|---------------------------------|--------------------|-------------------------|-------------------------|------------|
| | 100 dry basis | 10 dry basis | 10 per cent moist | 50 per cent moist | 0 moist |
| Clay | 164 | 2,404 | 0.037 | 11,820 | 18,027 |
| 2 day + 1 quarter | 30 | 477 | 0.204 | 12,203 | 18,206 |
| 1 day + 2 quarters | 85 | 1,292 | 0.403 | 10,122 | 18,011 |
| Quarter | 107 | 1,597 | 0.397 | 6,070 | 9,070 |
| 5 day + 1 hour | 64 | 784 | 0.704 | 2,704 | 6,027 |
| 1 day + 2 hours | 219 | 3,010 | 1,704 | 4,204 | 1,027 |
| 1 hour | 115 | 1,404 | 1,004 | 1,004 | 407 |
| Unburned loam | 85 | 220 | 770 | 1,610 | 2,101 |
| Unburned loam gravel 5-9 mm. | 63 | 85 | 110 | 410 | 1,245 |

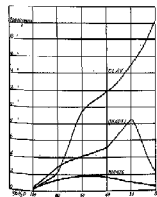


FIG. 10.—The effect of moisture, loss, and residue on the residue of soil.

The relationships directly spoken of are especially well shown by the curves (see Fig. 21), particularly the effect of the moisture content on cohesion. In a heavy soil the cohesion increases steadily from a saturated condition until dryness is reached, the increase becoming accelerated as the percentage of moisture decreases. This is because

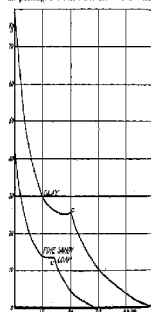


FIG. 21.—The cohesion curves of clay and the sandy loam at various moisture contents. (C), point at which soil changes to sand.

the binding power of the colloid material is gradually weakened by desiccation. In a coarse soil such as *gabra*, in which there is very little colloidal matter, the cohesion is weakened principally by the wear line. As this line, its pulling power increases and the curve ascends; but when the soil dries this line drops and the curve drops again, having no residual binding material. The same relationships are shown by curves (see Fig. 22) adopted from recent observations by Atterberg.¹

(11. *Moisture limits for successful tilage.* - In heavy soils in which the colloidal content is usually high, plasticity and cohesion also are high. This means that the soil when too moist will be pulled by tillage implements, especially such as the plow, and when too dry churning will occur because of very high cohesion. A moisture limit must therefore exist on a heavy soil, within which successful plowing may be done and maximum production results may be secured. That this moisture limit is curves 1) cohesion, since high cohesion and high plasticity bound it so closely on other hand. Such a relationship must be kept in mind not only by the farmer but by the technical man as well, since so much depends in any work upon good soil tilth. The relationship is clearly shown by the following curves (Fig. 23) partially adopted from Atterberg.¹ The cohesion and plasticity curves are seen to cross near the center of the diagram and indicate the existence of a zone when neither is exceedingly high or low.

In a day will a study of the optimum moisture con-

¹Atterberg, A. De Färdigsten Yrkes för Mänskheten, Morsen, 1914, 2. Stockholm, Band 17, Hett 1-3, Sida 415-421, 1914.

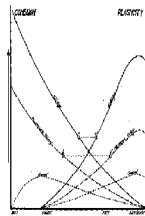


FIG. 15.—Diagram showing the reaction limits for a small change in the initial state. *a* and *b* represent the reaction limits which would be obtained if the reaction were to proceed in a day and hence day respectively.

It is necessary in order to determine what is just the right mixture content for good plowing. That this condition must be carefully gauged and immediate use made of the advantages it offers is shown by its narrow limits. A few days may suffice for the mixture to drop through such a narrow area of fluctuation. A day and is so difficult to handle at best that no opportunity such as afforded by optimum conditions should be lost. Moreover, a heavy well-plowed day or two does not regain its normal granular condition for several seasons. In a word, well as such difficulties are encountered.

Since the soil has low cohesion, plowing when it is too dry will not clod, while, because of low plasticity, little puddling will occur if tillage is too frequent when the soil is wet. Being always rather loose, such a soil is often benefited by plowing when it is slightly wet, the puddles being brought into close contact and excessive permeation being stopped while at the same time the water capacity is raised.

224. Control of cohesion and plasticity. It is evident not only that cohesion and plasticity control the successful tillage of the land, especially when the soil texture is fine, but also that these same factors vary with the moisture and the granular structure of the soil. It has been shown that there is a sensitive zone in all soils—this being narrower the finer the soil texture—or which rather cohesion and plasticity is sensitive. In this zone a heavy soil may be successfully plowed, while favorable to the structural condition of the soil. Since the processes of consolidation have already been shown to have cohesion and plasticity, it is evident that as much structure is developed the moisture zone for proper plowing will be widened, especially in a heavy soil. This is a very important point in the handling of clay and clay loams, since it not only opens a way for the elimination of the dangers of bad structural relationships, but also provides for putting the soil in a condition for easier and more convenient tillage. In a sandy soil, particularly where loamy is the granulating agent, a soil with more cohesion, more plasticity, and a greater water-holding power is developed, all of which tend toward a better medium for plant growth. Methods of developing this granulation thus become the logical logic for further discussion.

120. *Soil tilth.*—The previous data and discussion have clearly shown the very great importance of a good structure in the working of the soil in the field. Since good physical condition will reflect itself on crop yield, it is evident that structure must ultimately be considered in relation to all plant growth. This relationship is usually expressed by the term *tilth*. While structure refers to the arrangement of the particles in general, and granulation is a particular aggregate condition, *tilth* goes one step further and includes the plant. *Tilth*, then, refers to the physical condition of the soil as related to crop growth. It may be poor, medium, good, or excellent, depending to some extent. Good *tilth* may be said to mean well granulated granulation, in other words a well-developed granulation. Maximum *tilth*, always implies the presence of water, since the best physical relationships cannot be developed without optimum moisture conditions.

From the curves already presented, it is evident that an optimum moisture condition exists for the proper tilth of a soil, especially one of a heavy character. Also, an optimum moisture condition must exist for proper *tilth*, and therefore for proper plant development, since adequate *tilth* is the best physical condition for crop growth. Practical experience and theoretical evidence¹ have shown that these two optimum conditions as indicated in nearly all cases, a happy coincidence in the practical management of a soil. The optimum moisture condition for plant growth, then, is the proper moisture condition for effective plowing. The optimum condition

¹Quackenbush, F. H., and Hildebrand, F. B. *Soil Moisture Control and Physical Condition of Soils*. U. S. D. A., Bur. Soils, Bul. 35, p. 8, 1928.

for developing a favorable crumb structure is obviously the optimum moisture content for the development of the highest ϕ value. In fact, it can be stated with certainty that the optimum moisture condition for plant growth is the optimum for all favorable soil conditions, whether physical, chemical, or biological. Consequently, then, based on the vital factor in placing the soil in a physical condition such that the highest ϕ value, that physical condition which every farmer should strive for, may be developed in any soil. Until proper granulation is reached, no soil can be expected to yield maximum paying returns.

21. **Granulation.**—While it is possible to list the factors that bring about granulation in a soil, it is difficult to state specifically just why this phenomenon takes place. It has been suggested that much of the granule formation in the soil is due to the contraction of the moisture film around the particles when, for any reason, the moisture content is reduced (see Fig. 20). It is known



Fig. 20.—A, pulled out; B, submerged in soil.

that the soil particles tend to be drawn together by this moisture in the soil molecules, that is the pulling force of the film of water. If we discontinue to add a material which tends to swell, and only a drying power or loss of moisture, but retain a binding conforming power when dry, all

the conditions for successful granulation are present. The worst here is found in the colloidal material present in considerable quantities in heavy soils. These are the same fibres that have already been shown to determine the cohesion and plasticity of the soil, except that in granulating operations they are localized at contact points, and churning or puddling is thereby prevented. It is evident that if cohesion and plasticity forces are to function for granulation—*as, in other words, locally in the soil instead of generally and uniformly as when churning or puddling occurs*—a certain moisture content must be maintained. From what has already been shown, it is hardly necessary to state that this moisture condition is near the optimum moisture content for plant growth.

Warington¹ attributes granulation to unequal expansion and contraction of the soil mass, due to the imbibition and loss of water. In a soil subject to such a condition, the cohesive forces being localized, the internal strains and pressures are unequal and a tendency arises for the mass to divide along lines of weakness into groups of particles. The binding capacity of colloidal material, as well as of salts deposited from the soil solution, tends to make such a crumb structure more or less permanent. Tillage operations, development of roots, burrowing of animals and insects, the presence of humus, and the formation of leaf crystals, may serve to further developing these lines of weakness in the soil mass, on which the tension of the moisture films around the soil particles is brought to bear. The flocculation of soil particles may also develop lines of cleavage by their aggregation around

¹Warington, R. *Physical Properties of Soils*, pp. 23-25, Oliver, 1900.

surface centers. This movement of the soil particles is in every way facilitated by the presence of a moderate amount of moisture.

121. *Force facilitating granulation.*—Granulation is nothing more or less than a condition brought about by the force exerted by a variable water film and the packing and binding capacities of colloidal material, operating at a molecular level of force. It is evident that any increase or change in the soil which will cause a greater localization of these operative forces will promote increased granulation. The addition of materials from extraneous sources is also a practice that may tend to develop lines of resistance and thus cause a more intense localization of the forces at work.

The conditions, activities, and processes tending to develop or facilitate a granular structure in soils may be listed under six heads: (1) wetting and drying of the soil, (2) freezing and thawing, (3) addition of organic matter, (4) action of plant roots and animals, (5) addition of lime, and (6) others.

122. *Wetting and drying.*—The drying of a soil has been shown to result in a drawing together of the particles into aggregates. When this process is repeated again and again by alternate wetting and drying, the influence on granulation becomes marked.

In drying, the small particles are forced into the spaces between the larger ones, thereby reducing the volume as is shown by the cracks produced. These cracks that result from shrinkage are due to the capillary contraction. There comes a time when the general film around the whole mass must rupture, and it breaks along the lines of least resistance. If the soil mass is very uniform, there will be few breaks and the shrinkage will be mainly through

a relatively low content. This process produces what, on "concrete" granules. If there are numerous lines of weakness, however, there will be many centers of destruction, and consequently a larger number of small clods or granules will be formed. This is the desirable condition and constitutes good tilth—that is, the most favorable physical condition for plant growth.

Just what may be the effects of wetting and drying on the colloidal matter of soil is a question. In general, desiccative tends to decrease activity and in many cases their binding power becomes highly developed thereby. If such effects are irreversible, as many in the soil undoubtedly are, this binding becomes more or less permanent, which explains the tendency for a crumb structure to persist. Wetting, on the other hand, tends to develop colloidal matter which will become binding material on the next drying. The desiccation and throwing down of colloids, as well as their generation, thus becomes a very important factor in the wetting and drying as related to granulation.

The following figures¹ represent the relative ease necessary to pulverize puddled clay dried once, as compared with the same puddled soil wet and dried twenty times. The relative hardness may be taken as a rough measure of granulation:—

| | Percentage of gas index |
|--|----------------------------|
| 1. Puddled clay dried once | 100.0 |
| 2. Puddled clay dried twenty times . . . | 51.4 |
| 3. Puddled clay dried twenty times . . . | 38.6 |
| 4. Puddled clay dried twenty times . . . | 32.0 |

¹Hopkin, R. O. Some Causes of Soil Desiccation. Trans. Assoc. Soc. Agron., Vol. 2, pp. 228-232, 1912.

The fact illustrated above has many practical applications. It should be observed that the change in structure is not associated with constant volume, nor is it associated with a constant dry state. In neither condition is any force brought to bear on the particles. The force is exerted only during the drying process and the wetting process. It is a well-known fact that soils which are critically wet are usually in bad physical condition. In the change of wet land, it is found that the soil is at first very refractory; but when good drainage is established, there is a gradual amelioration of the physical condition, which is primarily a change in structure. On the other hand, in a soil continuously in a dry state there is no change in granulation. The improvement of soil structure, as a result of changes in the moisture content, is dependent largely on lines of weakness in the soil mass. Some of these are produced in the process of drying, and others in the very slowly formed.

184. Freezing and thawing — As will be seen in the consideration of soil moisture, the water is distributed in the free space of the soil. When it freezes it forms large, needle-like crystals. This crystallizing force is very great, amounting to about 150 tons when a cubic foot of water changes to ice. In freezing, the crystals gradually grow first in the larger spaces. During this process there is a marked withdrawal of moisture from the smallest spaces, so that the ice crystals in the large spaces may be built up. The soil mass is separated by the crystals, and as the result of such a single hard freeze a wet, puddled soil is fractured into pieces. The separation of the pieces by subsequent freezing and thawing will further break up the soil by creating new lines of weakness. The granulating power of freezing and thawing is shown in the following

figures¹ expressed in the relation given necessary to produce a puddled clay treated in various ways:—

Percentage
puddling

1. Puddled clay dried once 100.0
2. Puddled clay broken once and dried once . . . 28.1
3. Puddled clay broken three times and dried once . 77.2
4. Puddled clay broken five times and dried once . 33.8

Freezing probably affects fine siliceous material in the same general way as does drying. This has been indicated by the work of certain investigators² in which it was found that lowering the temperature of a soil below freezing lowered the hygroscopic coefficient.

124. *Addition of organic matter.*—Soils rich in humus or decomposed organic matter are generally in better physical condition than soils low in organic content. The useful effect of the decay of this material is very conspicuous in soils in well known. For example, in much of the western New York till region, the soils are now recognized to have a very different relation to crop growth from what they had for a few years after they were cleared. Their color has become lighter, and with the decay of the humus a decided physical change has taken place in the soil, which in to some extent remedied by the reticulation of the organic content. In certain places with the effect of humus depletion on clay:

¹Wright, R. G. Some Causes of Soil Crustation. *Trans. Amer. Soc. Agron.*, Vol. II, pp. 109-121, 1908.

²Cherniak, W. Das Verhalten der Bodenanteile der Pflanzendünger bei den physikalischen Bodenveränderungen durch Frost, Kälte, und die Bepflanzung neuer Böden. *Landw. Jahrb.*, Band 76, 1845-46, 1896-72-136. 1912. Also, *Bericht der 2. vom. Versammlung der Pfl.*, von. Die Veränderung der Bod. Boden. *Jahrb. C. Landw.*, Band 81, 1846, 2, 189-90-72-95. 1912.

part is even more modest. While the actions of hares are many, as has already been shown, its relationship to physical conditions is always particularly unimportant.

Brown contains much related material and in this way possesses a certain degree of plasticity. It is, however, of a very loose structure and therefore gives no relative lines of evidence. Another property of brown is that it undergoes great change in volume when dried out—a property which is fundamental to soil, producing large shrinkage cracks. This is noticeable in many black clay soils, which crack extensively. The great capacity of hares for moisture permits a wide range in moisture content, which produces corresponding physical alterations. This wide range from one extreme to another is a potent factor in generative influences. The ratio of the hare to the soil, and thereby increases the rate of change from the wet to the dry state by increased susceptibility of moisture. The relative effects of moist soil, and the amount of water from the main trunk, on the relation of a possible dry, as indicated by the lower required for a volume penetration of a hareship, is shown in the following table; the samples were dried and resented twenty times:

PERCENTAGE OF WATER IN HARE

| | Percentage of penetration |
|---|------------------------------|
| 1. Clay | 100 |
| 2. Clay plus 5 per cent of water | 82 |
| 3. Clay plus 15 per cent of water | 73 |
| 4. Clay plus 25 per cent of water | 56 |
| 5. Clay plus 30 per cent of water | 50 |

Figure 10. 10. Data from the Soil Laboratory. Trans. Am. Soc. Agron., Vol. 4, pp. 106-112, 1910.

TABLE 11.10 Effect of Rooting

| | Percentage of roots in soil |
|---|-----------------------------------|
| 1. Clay | 30 |
| 2. Clay plus 1 percent of cement | 40 |
| 3. Clay plus 2 percent of cement | 50 |
| 4. Clay plus 4 per cent of cement | 60 |

238. Action of plant roots and animals.—The extension of plant roots changes the soil structure by forcing the particles apart at each growing root point, and possibly also by some action yet to be explained. Grass, like prairie, is their effect on soil structure. Grass, millet, wheat, and other plants with fine roots are more beneficial to O.H. than coarser or tap-rooted plants such as corn, oats, and beets. Grass affects structure also by protecting the surface of the ground. It is advisable to establish a rotation on clay soil, that plowing may be done at the great intervals that plants with different root developments may be given an opportunity to exert their influence. The organic matter left in the soil by decaying roots is always in very intimate contact with the soil grains and has much to do with accelerating granulation.

Animals also affect soil structure. Furthermore, by carrying materials to the surface, exert a mixing effect, while the lines of escape and zones of weakness developed through their burrowing, preliminary use of so many important. Fences, especially wire and other barbed wire, are used in this and in other ways.

*Purdue B. O. Some Causes of Soil Consolidation. Trans. Amer. Soc. Agron., 1912, 3, pp. 386-422, 1912.

197. *Addition of lime.*—One of the important effects of lime is its flocculating action. This agglomeration, as already explained under collods, is the drawing together of the fine particles of a soil mass into granules. When caustic lime is mixed with water containing fine particles in suspension, there is almost immediately a change in the arrangement of the particles. They appear first to draw together in light, fluffy groups or floccules, which then rapidly settle to the bottom so that the supernatant liquid is left clear or nearly so. This phenomenon is termed flocculation, because of the groups of particles. It is not an action limited to caustic lime alone, however, but because of the confidence of this compound in other ways, and because of its very strong action, it is especially used on soils. This flocculating tendency when caustic lime is added goes on in the soil as well as with suspensions, although more slowly. In general the lime serves to modify the absorptive capacity of the soil itself material, and by drawing down these colloidal hydrates lines of weakness. The cohesive power of the soil is then localized and granulation most necessarily occurs.

The various forms of lime differ in their granulating capacities, sodium caustic and calcium hydroxide being very active while calcium carbonate is relatively inactive in this regard. For this reason, if flocculation effects are desired, the oxide or hydroxide combinations are added. The relative influences of various powdered clays presented by granulation is shown in the following table.¹ The soil was dried once and the untreated soil was used as 100 per cent.

¹Payson, R. O. Some Causes of Soil Consolidation. Trans. Amer. Soc. Agron., Vol. 2, pp. 106-121, 1908.

| | Temperature of pots °F. |
|---|-------------------------------|
| 1. Puddled clay | 130 |
| 2. Clay plus 2 per cent CaO | 46 |
| 3. Clay plus 4 per cent CaO | 46 |
| 4. Clay plus 6 per cent CaO | 31 |
| 5. Clay plus 8 per cent CaO | 36 |
| 6. Clay plus 10 per cent CaO | 31 |
| 7. Clay plus 25 per cent CaO | 35 |

* In the soil the acids and hydrates revert to the carbonates, but before this change occurs the fertilizing effects have been exerted and the lines of weakness so essential to granulation processes have been developed. Lime only does not produce granulation in a normal soil through its own action alone, but is aided by the other influences already discussed.

Washington¹ reports a statement of an English farmer to the effect that by the use of large quantities of lime on heavy clay soil he was enabled to plow with two horses instead of three. It is generally true that soils rich in lime are well granulated, and maintain a much better physical condition than soils of the same texture that are poor in lime.

126. *Clayage*.—The effect of clayage on soil structure is to produce lines of cleavage, and these, when produced by plowing, are multitudinous and fairly uniformly distributed. Plowing, when the moisture content is suitable, tends to break the soil into thin layers, which come one over the other like the leaves of a book when the page

¹ Washington, R. *Physical Properties of Soil*, p. 25, 1902, 1906.

are laid. The disturbance of the existing arrangement of particles puts in motion the two forces that have already been discussed, the pull of the water film and the binding power of the colloidal matter. The strength of cohesion between small particles, such as clay, can be realized when we consider the tenacity with which these particles are held together in dried yam-dried soil. This cohesive attraction is inversely proportional to the square of the distance between the centers of the surrounding helix. Particles that can be brought so closely together as one clay particles may be thus held with great firmness. The effect of fillings when an excess of water is present is to force the particles into larger masses and bring about a generalized cohesiveness of the masses of plasticity. The soil then becomes puddled. When the soil is too dry results either in chalking or in the soil's becoming so pulverulent that it becomes puddled on wetting. As already explained, proper pulverization by tillage, especially by plowing, may occur only when the soil is in optimum moisture condition.

10. The action of the furrow. The plow brings about its effect because of the differential stresses set up in the furrow slice as it passes over the share and the moldboard. The soil in immediate contact with the plow surface is compressed by friction, and the layers above tend to slide over one another much as the leaves of a book when they are bent. If the soil is in just the right condition, maximum pulverization results; but if the condition is too high or too low, puddling or chalking may follow, especially on a heavy soil. Not only does a churning occur, but this churning is differential, due to the slope of the share and especially to the curve of the moldboard. Where the soil is to be turned over with the best expenditure of

form, the share is sloping and is set to deliver a slanting cut, and the moldboard is long and gently inclined. This allows the furrow slice to be turned with little penetration and a minimum expenditure of energy. When constant granulation and pulverization are desired, the moldboard is short and sharply turned, and the share is less sloping and the cutting edge is less slanting. Such conditions make for the development of more friable and the generation of fines, increased tilling and sloughing stresses necessary for good granulation. The sharper the leading of the furrow slice, the greater are the lateral stresses set up. With the plow in the very best pulverizing agent when optimum soil moisture conditions prevail. It is also a most effective soil-filling agent when the soil is wet. Therefore care in the judging of optimum conditions for plowing is a most important feature in the maintenance and encouragement of soil granulation and tilth.

120. *Moisture*.—The factors controlling the structural condition of any soil are found to be plasticity and cohesion. As these increase, the tendencies of a soil to pull apart when wet and to clod when dry are augmented. Therefore, in heavy soils a decrease in these factors is desirable, through a careful control of moisture and a breaking of the granular structure of the soil. Granulation, while due to some extent to the residual influence of the water film, is traceable largely to the colloidal matter which acts as a binding agent. It is really a concentration of the forces of cohesion and plasticity around numerous localized foci. Granulation takes place under the influence of wetting and drying, heating, plants and animals, addition of humus and lime, soil tillage operations, especially plowing. Due to the high cohesion and plasticity of heavy soils, the modulus are

for successful plowing is relatively narrow. The ability to detect when this zone has been reached is a key skill in one of the essentials of successful soil management. Just as essential is the effective mixing of such a zone by granulation operations. The optimum moisture condition for tillage is also the optimum condition for plant growth—a happy coincidence, since by regulating the moisture content for plant development conditions are rendered most favorable for all soil activities. It is thus possible to realize that criterion in all soil physical operations, a maximum yield.

CHAPTER XI

THE FORMS OF SOIL WATER AND THEIR MOVEMENT

Upon all normal conditions the soil bears a certain amount of moisture, which must be reckoned with in any study whether of a practical or of a theoretical nature. Moreover, the amount of water varies in its distribution according to its position. It also has movement, which goes far in determining its usefulness to plants. Before a discussion of the different forms of water, their movement, and their availability to plants, may be considered into, however, some way of quantitatively stating the amounts present must be determined upon.

131. *Methods of ascertaining soil moisture.*—During the many years of soil investigation, especially where the problems had to deal either directly or indirectly with moisture, five methods of water expression have been evolved, their use depending on the nature of the work and on the points to be expressed. These may be listed under two general heads:—

A. Percentage expression

1. Percentage on a wet basis
2. Percentage on a dry basis

B. Volume expression

1. Cubic inches to the cubic foot of soil
2. Percentage by volume
3. Surface inches

The simplest way of explaining the application of these methods for the expression of the amount of water in a soil is by a specific case. Suppose a certain soil in field condition weighs 100 pounds to a cubic foot and carries 10 pounds of water. Obviously it would contain 10 per cent of water by the wet method of calculation, or 33.3 per cent of water, using the *shrinkage dry* soil as a basis. A pound of water contains 27.6 cubic inches; therefore the amount of water carried by this soil expressed by volume would be 276 cubic inches for every cubic foot of soil. The percentage by volume would equal $(276 \div 37234) \times 100$, or about 0.7 per cent. A half-inch of water covering the top of a cubic foot weighs 3.2 pounds. Obviously the number of surface inches which this 10 pounds of water would occupy if placed on the top of the cubic foot of soil would be $10 \div 3.2$ or 3.12 surface inches.

The first method of moisture expression, as percentages on a wet basis, is open to two serious objections. In the first place, two different percentages of water in different samples of the same soil do not represent the same degrees of wetness as are expressed by the percentages. For example, 100 grams of wet soil containing 5 per cent of water would consist of 5 grams of water and 95 grams of soil, a ratio of 1 to 19. If the soil contained instead 10 per cent of water, the ratio would be 1 to 9 instead of 1 to 19, so the ratio of the percentages would naturally fail one to expect. The second objection is just as serious and arises from the fact that soils have different apparent weights. For example, 5 per cent of water on the wet basis for a clay weighing when dry 70 pounds to the cubic foot would equal 3.50 pounds, while 5 per cent on a sand weighing 100 pounds would give 5.00 pounds of the same volume. The error of such a method of expression is

obvious, not only in comparing the water content of the same soil, but in comparing different soils as well.

In using a percentage of moisture based on the dry soil instead of on the wet, the first of the above objections is eliminated. Consequently this method of expression is perfectly legitimate as long as soils having about the same apparent specific gravity are compared. As soon as soils of different weights are considered, however, a more nearly accurate method must be employed. Obviously, then, the only really rational mode of moisture statement is by the volume method. Its ordinary calculation of water, however, the proceeding by dry weight is generally used because of its simplicity and the facility of expression that it affords. It is also much easier to establish than a percentage based on volume.

The first and second methods of volume expression are of about equal value as far as direct comparison goes. For the actual water present the number of cubic inches (or a cubic foot of soil is perhaps preferable, to disclose the exact amount of water contained) and may easily be converted to pounds in a cubic foot or tons in an acre on the one way or the other. The third volume statement is generally used in field practice, especially in irrigated regions, where water is measured in inches or feet to an acre of area. Such a statement of the available water in a soil not only is convenient, but also gives a direct comparison with the probable rainfall of the growing season.

132. *Kinds of water in the soil.*—As has already been demonstrated, a soil of a definite volume weight has a definite pore space which may be occupied by air or by water, or shared by both, as the case may be. Of course, in that soil for plant growth is one in which there is both air and water, the proportions depending on the

system and the structure of the soil and the character of the crop. Assuming for the time being, however, that the pore space is entirely filled with water, or, in other words, that the soil is saturated, three forms of water are found to be present—hygroscopic, capillary, and free, or gravitational. These forms differ, not in their composition, but in the position that they occupy in relation to the soil particles.

The hygroscopic and capillary water are both like films; that is, they surround the soil particles, being held partly by the attraction of the particles and partly by the molecular attraction of the liquid for itself. The hygroscopic film is very thin, being water of condensation, or adsorption. When this film is satisfied and no more is left present, the capillary water film begins to form. The line of demarcation between hygroscopic and capillary water is not sharp. The general difference between the two forms may be considered as lying not only one of position, but also one of movement, this power being possessed only by the capillary film. With a change in any controlling condition, such as temperature, hygroscopic water may change to capillary, or capillary water to hygroscopic, as the case may be. As the capillary water continues to increase and the film becomes thicker and thicker, a point is at last reached at which gravity overcomes the surface tension of the liquid and drops of water form which tend to move downward through the air spaces, being now subject to movement by the attraction of gravity. Free, or gravitational, water then also becomes present in the soil. If water is still added, the gravitational water continues to increase until the air is almost entirely displaced and a saturated condition results. There may be a change of capillary to free water

or of free water to capillary with a change of structure, temperature, or pressure, as may now be the case between the hygroscopic and capillary moisture. The forms of water present in a saturated soil may be conveniently represented by the following diagram:—

HYGROSCOPIC, CAPILLARY, & FREE

FIG. 10.—Diagram representing the three forms of water that may be present in a soil.

100. *Hygroscopic water*.—The hygroscopic water in a soil has been spoken of as the water of condensation, or adsorption. It is, however, quite distinct from water condensed on a surface colder than the atmosphere in which it is placed. All bodies possess the power, to a greater or less degree, of adsorbing water even when at the same temperature as the air with which they are in contact, provided, of course, that the air contains water vapour. The hygroscopic film may be continuous or only partly continuous, depending on the condition of the surface. In fact, the movement of water over surfaces is often greatly facilitated by an already existing hygroscopic film. Thermal conditions being constant, the amount of hygroscopic water of various materials is determined by two factors: (1) the characteristics of the material itself, and (2) the amount of surface it exposes.

It is a well-known fact that various materials differ in the amount of hygroscopic water they will hold, due to the attraction of the substances themselves for water. The difference in the distances of the film is so slightly altered, however, by differences in materials, that, after factors being constant, the hygroscopic water becomes a function almost entirely of surface. Glass becomes

for more hygroscopic when pulverized. Porous bodies are especially high in hygroscopic water, sometimes holding as much as 20 to 30 per cent of moisture. The following data, drawn from Aronson¹ and von Debesch,² although no doubt faulty, illustrate the differences in hygroscopicity of materials commonly found in soils and make plain the complexity of the question when applied to soil phases.—

PERCENTAGE OF HYGROSCOPICITY IN DIFFERENT SUBSTANCES AT 27° C. FROM DEBESE AND VAN DER VEER

| | Water | Free Moisture |
|-----------------------|-------|---------------|
| Plum | 15.96 | 85.04 |
| Peach-stone | 18.70 | 50.41 |
| Walrus | 2.0 | 3.25 |
| Quartz | 2.0 | 4.2 |
| Opals | 3.0 | 1.7 |

One of the characteristics peculiar to colloids is their ability to adsorb water in a high adsorptive power for water, this giving them properties not usually possessed by crystalline substances. Colloidal precipitates of silicic acids, ferric oxide, and aluminum oxide are good examples. Colloidal humus, gelatin, and agar are noted for their adsorptive powers. The water in such cases is not simply adsorbed on the external

¹ Aronson, Georg. Untersuchungen über die Osmotischen Eigenschaften der Dehnungsänderungen für den Pflanzensystem. *Ann. Phys. Chem.* 1871, 1, 107.

² Debesch, A. P. von. Untersuchungen über die Osmotischen Eigenschaften und die Hygroscopicität der Dehnungsänderungen. *Ann. Phys. Chem.* 1871, 1, 107.

expanses, but is distributed over the great internal surface exposure. Such water cannot be expelled by ordinary drying, but the material must be subjected to a high heat in order to drive off even a part of the water so held. The question is greatly complicated also by the fact that some bodies have a chemical affinity for water. This results in the formation of hydrates and other salts. Such water cannot be expelled without the breaking-up of the compounds.

Ordinary soil possesses to an extraordinary degree the three characteristics already cited: that is, it exposes a very large amount of free surface; it tends to generate continuously large amounts of colloidal material such as ferric hydrate, aluminium hydrate, silicic acid, and especially humic materials in a colloidal state; and it always has present compounds having an affinity for water. However, since these compounds are easily satisfied, and also since the adsorptive power of colloids is due to the surface exposed, it may be considered that, other conditions being equal, the hygroscopicity of the soil is essentially a surface phenomenon. Although for all practical purposes hygroscopicity may be considered as having special relation to surface, exact correlation is not easy partly because of the difficulty of accurately determining the surface exposed by a normal soil.

134. Effect of texture and humus on hygroscopicity.—The question being thus reduced to a surface consideration, it is evident that the texture of the soil, external factors being under control, is the determining factor. The following figures from Loughridge,¹ by whom the hygroscopic

¹Loughridge, R. H. *Investigations in Soil Physics*. California Agri. Exp. Sta., Rept. of Work of the Agri. Exp. Stations of California for 1892-3-4, pp. 70-77.

constant was determined by exposing the soil to 12° C. in a saturated atmosphere and then drying at 200° C., following this point:

HYGROMETRIC CONTENTS OF VARIOUS SOILS

| Soil | For every Gram of Soil, the Weight of Water in Hygrometric Moisture, expressed in per cent of Soil | Percentage of Colloidal Content |
|-------------------------|--|---------------------------------|
| 1) clay | 11.27 | 21.65 |
| 2) clay loam | 11.15 | 6.95 |
| 3) loam | 12.05 | 5.85 |
| 4) sandy loam | 7.31 | 2.51 |
| 5) sand | 2.95 | 2.31 |

Apparently, the finer the soil, the greater is the hygrometric capacity. The finer the soil, the higher also is the percentage of clay, and consequently the greater is the amount of material likely to be present in a colloidal state. As a matter of fact, the hygrometric moisture as shown above is roughly proportional to the clay; and so clay, especially the finer forms, is largely colloidal in nature, the colloidal content of a soil practically indicating the hygrometric content. This fact is the basis for Minkowski's¹ method of colloidal estimation, in which hygrometric moisture determined under certain controlled conditions is used as a relative measure of colloidal content. The various grades of particles constituting the total make-up of sand, clay, do not possess the same weight in the determination of hygrometricity, the finest grade being clay, especially that part which has, by either physical

¹ Minkowski, E. A. The soil, paragraph III.

or chemical means or both, been thrown into a colloidal condition. Repeatedly do the laminae collapse, so that they already have shown, function in this respect, so that the organic matter must be of very great importance in determining the hygroscopic capacity of any soil. The freer the soil, the greater is the amount of hygroscopic water merely because of the large area of surface exposed. Also, very particles that will absorb the colloidal material — its laminae entirely being very susceptible to increase by proper soil management — the higher will be the percentage of this hygroscopic moisture. Therefore and hence, then, governs the hygroscopicity of most soils.

136. *Nature of the film.* — The nature of this thin film which is designated as hygroscopic water has not as yet been determined. Held so strongly by a molecular force averaging probably 10,000 atmospheres, generated by cohesion and adhesion, it is not definitely known whether the film exists as a liquid or a vapor. Consequently it cannot be expected to conform to the laws that are generally found to apply to capillary films. In many cases the film may not be continuous, and being so very, very thin, it may even possess a negative surface tension. The radius of curvature of a particle in water has been shown by Chaudhury¹ to be about 1.5×10^{-7} centimeters. Within this zone the molecules of water are much restricted in their motions. The thickness of the hygroscopic film on quartz particles as calculated by Briggs² is 1.05×10^{-6} centimeters, showing that the entire edge of the hygroscopic

¹Chaudhury, C. W. *The Nature of Molecular Attraction*. Physical Review, Vol. 31, pp. 275-285, 1933.

²Briggs, L. J. On the Adsorption of Water Vapor and of Organic Solids in Inorganic Solids. *Proc. Roy. Soc. London*, Vol. 11, pp. 467-481, 1925.

the water in a large vessel from its movement, is considerably reduced this zone of influence. In order to give an idea of the extreme minuteness of the hygroscopic film, it may be said that its thickness is less than the diameter of the smallest known cell bacteria. In going from the surface of a particle outward through an ordinary water film, passage is first made through the zone of infection. When the edge of this is reached, as soon as passage through which molecules can gradually expanding capacity be molecular motion until the outer edge of the hygroscopic film is crossed, where molecular activity reaches its maximum.

IX. Effect of humidity and temperature on hygroscopic water.—The external conditions seem to affect the amounts of hygroscopic water that a soil may hold under definite conditions—humidity and temperature. As a general rule, the higher the humidity, the higher is the hygroscopic moisture. The experiments of von Felsko¹ with quartz and bones illustrate this point:

Percentage of Moisture Water held on Various Humidities under an Air-saturation in Vacuum-dried Bones at 20° C.

| | Relative | to | to | to | to |
|--------|----------|---------|----------|----------|---------|
| | Humidity | the air | Air-sat. | Air-sat. | Percent |
| Quartz | 100 | 100 | 100 | 100 | 115 |
| Bones | 100 | 100 | 100 | 100 | 100 |

The results as to the effects of a rise in temperature on the hygroscopic film are not so definite. Most in-

¹ Felsko, A. P. von. Untersuchungen über die Abhängigkeit des Wassergehalts der Zellenmembranen von der Feuchtigkeit der Luft. *Zeitschrift für physikalische Chemie*, 1890, 1, 1-10.

weights¹ find that as the temperature is increased the hygroscopicity becomes lowered, thus following the general laws of adsorption. Hilgard, however, obtained opposite results when the air was saturated, although his data agreed with previous results when hygroscopicity was studied in an atmosphere unsaturated as to its capacity for water vapor. King² explains this discrepancy as being due to the very high vapor pressures generated by a saturated atmosphere at high temperatures, causing a more rapid evaporation of water by the soil than was lost from its surface. The time necessary for a soil to acquire its maximum thickness of adsorbed water is uncertain. Hilgard³ used seven hours in his determinations, while Macfarland⁴ exposed his soil for several days. It will continue to increase its weight slowly as its time of exposure to moist air is increased, so that a sharp line of demarcation between capillary and hygroscopic water is difficult to establish. Capillary water may even be present in the minute interstices between the hygroscopic film is completely satisfied.⁵

137. *Determination of hygroscopicity.*—The method of the determination of the maximum hygroscopicity of a soil, or, in other words, the hygroscopic coefficient, is simple in outline. The soil, in a thin layer, is exposed

¹ Patton, H. R., and Chubb, J. E. *Adsorption of Vapors and Gases by Soils*. U. S. D. A., Bur. Soils, Bul. 51, p. 25, 1905.

² King, P. H. *Physics of Agriculture*, pp. 126-128. Published by the author, Madison, Wisconsin, 1903.

³ Hilgard, E. W. *Soils*, pp. 196-201. New York, 1911.

⁴ Macfarland, E. A. *Botanically*, pp. 80-83. Phil. Mag., Dublin, 1905.

⁵ Briggs, L. J. *The Mechanism of Soil Moisture*. U. S. D. A., Bur. Soils, Bul. 61, p. 12, 1907.

in an atmosphere of definite humidity under conditions of constant temperature and pressure. Complications arise from the necessity of using a very thin layer of soil, from the difficulty of controlling humidity, and from the tendency of capillary water to form in the soil interfaces unless the hygroscopic film is modified. The question of how long the exposure should take place is a very serious factor, as has already been pointed out. In the drying of the soil after exposure a serious condition also is encountered, in that as the temperature is raised, the giving-off of water vapor continues. It is evident, therefore, that not only must any method be more or less arbitrary, but that its value can be only comparative. The method of Höltschlich, as already described¹ is probably the most nearly accurate. He exposes the dry soil under partial vacuum some 10 per cent sulphuric acid and water. The partial vacuum is to hasten absorption, and the acid to prevent a fully saturated soil, thereby causing close changes of low humidity.

III. Heat of condensation. The amount of energy necessary to reject the hygroscopic film from around a soil particle is very great, since its only movement is thermal. As a matter of fact, it is really impossible to find the soil grains entirely without causing the loss of moisture other than that simply absorbed. As so much energy is expended in removing this film, it is reasonable to expect that a certain amount of heat of condensation when the film is removed would become apparent. Paulsen² offers the following quantitative data concerning this point:—

¹Höltschlich, J. R. This Inst. *Proceedings* 111.
²Paulsen, E. K. *Heat Transformation in Soils*. U. S. D. A., Bur. Soils, Bul. 68, p. 26, 1908.

TABLE I
Heat Evolved in Various Acid-Base at 100° C.

| Acid | Heat evolved, kcal. or Cal. per mole |
|---|---|
| Chloroacetic acid | 150 |
| Phenyl dimethyl ether | 200 |
| Methyl iodide | 367 |
| Iodoacetic acid | 1108 |
| Chloroacetic acid | 5775 |
| Methyl iodide (5 per cent aqueous solution) | 6843 |

129. *Capillary water.*—It has been shown in the previous discussion that a large proportion of the hygroscopic film is beyond the radius of influence of the particle and is not held so rigidly as in the inner portion. In other words, in this film a certain amount of molecular movement is possible, this movement depending on the distance from the particle. As men, however, as the boundary of the hygroscopic film is crossed, a comparatively thick film of moisture is reached in which molecular movement, except for the influence of viscosity, is practically free and unimpeded. These two zones (see Fig. 31)—one in which capillary movement is more or less free, and a comparatively thin film in which molecular movement becomes increasingly dependent upon the radius of influence of the soil grain—is approached,—now there have clearly differentiated. The capillary water differs from the hygroscopic moisture (2) in that it is largely in a liquid state and consequently is governed by the ordinary laws of liquids; (3) in that it responds as ordinary



FIG. 31.—Diagram showing the relative thickness of the hygroscopic and capillary water films surrounding a soil particle.

(4) in that it is not so rigidly held as the hygroscopic moisture; (5) in that it is largely in a liquid state and consequently is governed by the ordinary laws of liquids; (6) in that it responds as ordinary

mercaptenes being held with less tenacity; and (4) is that it has the power of movement from place to place within the film, hence the name capillary water.

161. *Surface tension and the force developed thereby.*—The power that tends to hold this capillary water in place against the force of gravity, a constant, depends on the surface tension of the liquid. This phenomenon of surface tension is due to the existence of certain molecular forces acting from within. In a drop of water, for example, the particles are attracted equally in all directions and consequently are able to move with perfect freedom. The molecules on the surface of the drop, however, are not in such an equilibrium of attraction, since the pull of the water molecules within is greater than that of the air particles without. The resultant attraction is therefore inward, and is directed along a line perpendicular to the surface at that point. The result is the development of a more or less ideal membrane, the elastic force of which is not affected by the amount of the surface, but by the curvature. In a sphere the force is pressure developed by surface tension is equal to twice the surface tension divided by the radius. The increase of the elastic force by curvature of film is very important as regards soil water, since, as will be shown later, it governs the movement of capillary water from one particle to another, the direction of the movement being determined by a difference in pressure as developed by unequal curvatures of film surfaces.

As a result of this force developed by surface tension, the water film around a soil particle tends to equalize itself until this pressure is everywhere the same. On this force depends also the thickness of the capillary film. Under any given conditions this capillary film will con-

time to thicken until the mass of the water is so great as to allow gravity to come into play and pull enough water away to again restore the equilibrium. The soil particles would at this point be maintaining its maximum thickness of capillary film. It is also quite evident that as the capillary film is thinned — as, for example, by evaporation — the forces developed by surface tension would be increased, due to increased curvature of the film, and the difficulty of separating the external layers of the film would naturally become greater.

III. The form of water surfaces between soil particles. — In the case of a soil, however, the question of the capillary film becomes more complex, since a great number of different sized particles are present in nature or has close contact with one another. This means that under normal soil conditions the capillary film is continuous from one particle to another — a very different question to consider from that of a film about a single isolated soil



FIG. 22. The condensation and movement of the capillary film of soil particles when brought in contact. As left is shown the condition before condensation with a very much as it is; as right the film has broken in contact with a great thickness of it.

grains occur or has potential in shape. Supposing, for example, that two particles, each carrying a capillary water film, be brought into contact. As left is shown the condition before condensation with a very much as it is; as right the film has broken in contact with a great thickness of it.

facture — that at A, A' (see Fig. 23), with the separation of the original film, and that at B , which is very acute and which naturally must exert a very great outward pull. Under the stress of this pull developed by the surface tension acting in this film of very great curvature,

the water is drawn into the space between the particles, where it becomes thicker than the capillary film about the particles. The readjustment continues until the forces developed by the two film become equal. An equilibrium is now established. It is evident, then, that as the capillary water becomes less in a soil from any cause, the voids vacated in the space between the particles become larger and less, but still remain thicker than the films about the particles themselves. What percentage of the capillary water is held in the thickened coats of the soil grains cannot be calculated, but it is probable that this moisture makes up the major part of the capillary water of any soil. One of the errors in the determination of the hygroscopic coefficient of a soil, as already pointed out, arises from the tendency toward the attraction of capillary water in these angles between the soil particles (where the hygroscopic film on the grains themselves becomes widest).

142. *Factors affecting amount of capillary water.*—As might naturally be expected, the factors that tend to vary the amount of capillary water in a soil are several, and their study is necessary for a complete knowledge of the secondary influences that they may generate. These factors may be divided under four heads: (1) surface tension, (2) texture, (3) structure, and (4) organic matter.

143. *Surface tension and the amount of capillary water.*—Any condition that will influence surface tension will obviously influence the thickness of the capillary film, because of a relation in the forces thereby developed. A rise in temperature, by lowering the surface tension, would consequently lower the capillary capacity of the soil, and if the soil were capillary saturated would draw more of the water to become gravitationally in its

nature. A lowering of the temperature would make a change in the opposite direction. This theory has been verified by certain experiments by King,¹ in which he found, other conditions being constant, a very decided influence on capillary water through change of temperature. Weller² has shown that a depression of from 55 per cent to and to as high as 87 per cent in height may come from a rise in temperature of twenty degrees. The surface tension of a liquid may also be greatly changed by the addition of salts, and, since the soil always contains some material in solution, the surface tension, and consequently the capillary capacity, might be expected to increase. As a matter of fact, the soil solution is very dilute, and even if large amounts of fertilizer salts were added the attractive power of the soil would tend to maintain a very dense soil water at the surface of the film. Again, so human dense is continuously going on, only materials are probably produced which would tend to spread over the capillary film and greatly reduce their surface tension. Therefore, as far as is now known of the two varying influences, temperature change is by far the most potent in its influence on capillary capacity.

144. *Tension and the amount of capillary water.*—The force the texture of a soil, the greater is the number of angles between the particles in which a film of capillary water may be held; also, the actual amount of surface exposed by the particles is immensely larger than it is

¹King, P. B. *Fluctuations in the Level and Rate of Movement of Ground Water*. U. S. D. A., Weather Bur., Ind. A. No. 33-41, 1902.

²Weller, R. *Ergebnisse über die Wasserkapazität der Bodenstoffe*. *Beibl. z. Z. Chemie der Agri. Physik*, Band 5, Seite 364-375, 1896.

cause will. Due to these two conditions, a soil of fine texture will contain considerably more capillary water than one of which the texture is coarse. The maximum capillary capacity of a soil is not directly proportional to its porosity, as was roughly proved, to be the case with the hygroscopic coefficient. This is probably because the angle exposure between the grains increases in number as the texture becomes finer much faster than the actual surface developed by the particles are generated. The capillary water in any soil varies with the height of the column. This comes about from the gravity effects on the liquid surrounding the particle. If the liquid had no weight, gravity would not be a factor and the same thickness of film would be found at any point in a soil column. Such a condition would greatly simplify the study of soil moisture. It is a matter of particles (see Fig. 23) touching massive capillary films are brought together naturally, the weight of the whole surrounding film is drawn immediately into the capillary surfaces at the top. The capillary spaces of this point necessarily become depressed, so that they may attain a greater curvature and draw upon the water weight down on them. This curvature must be reduced to balance the pressure of the water below plus the weight of the water in the connecting films. The particles remain at the same time occupying a similar adjustment with a set of particles still below, being water in order to allow a change of



FIG. 23.—Diagram showing the adjustment of the capillary films to the weight of the water and the weight of the water in the connecting films.

structure. A thinning of these films results, but not so fast as what is in the particles above. The action continues in this manner through each capillary series until equilibrium is established, the change in thickness of film being less and less in each order to the transverse support of the films above. If the amount of capillary water present is too great to be supported by the films, enough is lost by gravity at the bottom to bring about equilibrium. The film is at its maximum at the bottom of the column, but decreases in thickness as the column is ascended, not only on the particles themselves, but in the angle interfaces as well. This is necessary, as each successive film must support an increased weight of water. It is, therefore, evident that it is impossible to assign any definite figure as to the capillary water capacity of a soil. Only relative or comparative data may be quoted. The following diagram

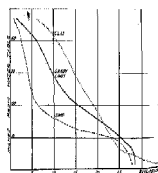


FIG. 34.—Diagram showing the distribution of moisture in capillary columns of soil of different textures. The wet of each soil column being equal.

(see Fig. 34) from Birmingham¹ makes also not only the influence of texture on capillary water, but also the distribution of water in a capillary column.

The final mean water content of these soils was 11, 15, and 20 per cent, respectively, for the fine sand, the sandy loam, and the clay; showing that as the texture becomes finer, the greater is the average capillary water content even after allowing for the differences in hygroscopic moisture.

164. Effect of structure on the amount of capillary moisture. — The structure of the soil, or, in other words, the arrangement of the particles, will become a factor in capillary capacity in so far as it affects the amount of effective capillary surfaces. Any arrangement of particles that will increase the number of angles of contact will certainly increase the amount of capillary water. The expanding of a loam soil will increase the possible capillary surfaces until all the interstitial space becomes capillary in its nature; further expanding will then cause a marked decrease. The granulation of a clay soil, by producing a more disordered and by actually increasing the effective surface exposure, tends to increase its water-holding capacity. At the same time the compacting of a sand, by increasing not only the actual effective surface, but also the number of angles possible for capillary concentration, will cause a rise in the capillary capacity of this soil.

In a study of this kind it is very evident that the cross-section of a long column should be considered, since the percentage of moisture at any one point is not indicative of the true capillary capacity of a soil. Both

¹Hardy, H. Studies on the Movement of Soil Moisture. U. S. G. A., Pac. Sect., Bul. 26, p. 22, 1907.

figures have been obtained by Buckingham¹ in his study of loose and compact soils. The following curves represent the general trend of his results:—

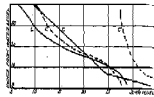


FIG. 15.—The effect of moisture upon the field value of moisture in soil by volume. (1) loose sandy loam, (2) loose sandy loam, (3) compact sandy loam, (4) compact clay, (5) humus clay.

While it is evident that the mean water content of the compact sandy loam is greater than that of the loose compact, the latter showed a higher percentage of moisture up to about the tenth inch. The clay shows a more marked effect from compacting, dropping in the compact sample almost as low as the sand, on the average, and showing at about ten inches from the end of the column a percentage of moisture sensibly lower than that of either the loam or the compact sand. It is obvious that the former may do much in the control of capillary water by generating a proper physical condition of its soil.

245. Organic matter and the amount of capillary water.—Organic matter, especially when it has been reduced to the form of humus, has great capillary capacity for retaining throughout the mineral constituents of the soil. Its primary affects are numerous internal and

¹ Buckingham, R. Studies on the Movement of Soil Moisture. U. S. U. S., Bur. Soils, Bul. 38, pp. 14-25. 1917.

less, while the colloids exert an affinity for moisture which causes its water capacity to a very high degree. Its tendency to swell on wetting is but a change in condition constant to an approach to its maximum moisture content. The following data, taken from a compilation by Stone¹ gives an idea of the capillary capacity of the soil organic matter:—

| | Percentage of water |
|---|------------------------|
| 1. Humus extracted from peat | 426 |
| 2. Non-wood content from peat | 165 |
| 3. Vegetable mould | 306 |
| 4. Peat | 190 |
| 5. Garden loam, 7 per cent humus | 86 |
| 6. Heavy garden soil | 37 |
| 7. Field loam, 3.4 per cent humus | 22 |
| 8. Mountain valley loam, 1.2 per cent humus | 27 |

Even after allowance has been made for the increased hygroscopic coefficient incident to an increase in organic matter, the effect of the latter is very strongly evident on the capillary capacity of a soil. Besides this direct effect, organic matter exerts a stimulus toward better granulation, a condition is itself favorable to increased water-holding power.

1st. *Determination of capillary water.*—The capillary water in a sample of field soil may be determined by making a Wadsworth test in the ordinary way for the total water contained. This represents the hygroscopic plus the capillary water. A determination of the hygroscopic coefficient on another sample yields a figure which when

¹Stone, P. E. *Agriculture*, Vol. 1, p. 106. New York 1912.

abstracted from the total water will give the capillary water present in the sample. The capillary water at various points in a soil volume may be obtained by subtracting the hygroscopic coefficient from the various percentages of moisture present, since the thin hygroscopic film is not influenced by height of column or ordinary structural conditions. In ordinary soils, however, the differences in hygroscopicity are not so great but that the total water retained in a soil volume against gravity serves as a very good measure of relative capillary capacity.

166. *The moisture equivalent of soils.*—Dienes and McLane¹ have perfected a method of comparing soils on the basis of their capacity to hold water against a definite and constant centrifugal force of one to three thousand times the force of gravity. The soils, in this case, are placed in perforated brass cups which fit into a centrifugal machine capable of developing the above force, and are whirled until equilibrium is reached. The resultant moisture percentage is designated as the moisture equivalent. It really represents the capillary capacity of a soil of minimum column height when subject to a constant and known force or pull. The lower the soil, the greater of course is the moisture equivalent. The authors also found that 1 per cent of clay or organic matter represented a relative power of about 35 per cent, while 1 per cent of silt corresponded to a retention of 15 per cent. Representative data which show the correlation of the moisture equivalent to the textural properties of the various types are given in the table on the following page.

¹ Briggs, L. J., and McLane, J. W. *The Moisture Equivalent of Soils*. U. S. D. A., Tech. Series, Bul. 45, 1927.

| Soil | The core weight in grams | The core height in centimeters | The weight of the water in the core | The weight of the water in the core | The weight of the water in the core |
|------------------------|-----------------------------------|---|--|--|--|
| 1. Marl & coarse sand | 19 | 17.7 | 2.3 | 4.8 | 5.1 |
| 2. Marl & fine sand | 16 | 20.5 | 6.1 | 6.5 | 6.1 |
| 3. Yellow loam | 15 | 25.4 | 6.1 | 10.1 | 10.1 |
| 4. Marly alluvial loam | 20 | 16.9 | 6.2 | 22.2 | 24.4 |
| 5. Marly clay loam | 37 | 23.9 | 4.5 | 16.1 | 22.6 |
| 6. Marly clay | 14 | 10.9 | 1.6 | 15.9 | 20.5 |

186. The maximum relative power of a soil.—Another determination has been derived by Hignett¹ and not to considerable extent by other investigators.² It is designated as the maximum relative power of a soil.

A well perforated brass cup is used, having a diameter of about 5 millimeters and capable of containing a soil column 1 centimeter in height. A short column is used, since it is only under such conditions that a soil may resist against gravity the greatest amount of water. Also, the soil is either equal or confined, so the same may be, on the assumption of water until an equilibrium is reached.

A stopper disk is placed in the aerial cup, and the soil is poured in, gently tamped down, and struck off level with the top of the cup. The cup is then set in water and the soil is allowed to take up its maximum moisture.

After draining, the weight of the wet soil plus the cup, together with the weights previously obtained, will allow the calculation of the total water contained by the soil.

189. Capillary movement.—It has already been shown how different thicknesses of films or two particles limit

¹Hignett, R. H. Soil, p. 200. New York, 1911.

²The text, paragraph 181.

to become equal, due to the pulling force developed by the angle of curvature between the particles. It is evident that differences in curvature must be the motive



force in the capillary movement of soil water. Let it be supposed, for convenience, that three equal spheres were brought in contact (see Fig. 30). The equal amount of water in all. The movement will place it in the position of (A) the top of the middle sphere. On the other hand, if the spheres are of different sizes, the water will move to the point of greatest curvature, until the pull at A and that at B become the same. Such an adjustment might go on over a large number of films, and if one end of the column was exposed to an evaporation of just the right rate and the other end was in contact with plenty of moisture, large quantities of water would be pumped by capillarity.

This capillary movement may go on in any direction in the soil, since it is largely independent of gravity, yet under natural field conditions the adjustment tends to take place very largely in a vertical direction. When a soil is exposed to evaporation the surface films are thinned and water moves upward to adjust the pressure. This explains why such large quantities of soil water may be lost so rapidly from an exposed soil.

Capillary adjustment may go on downward, also, as is the case after a shower. Here the equality of the adjustment is aided by the weight and movement of the water of percolation.

The capillary adjustment in a soil may go on under

two conditions: (1) if the soil column is in contact with free water; and (2) if no gravity water is present, the movement being merely from a moist soil to a drier one, an indispensable supply of water not being present. In the first case the lower portion of the soil is entirely saturated for a short distance above the free water surface, due to the functioning of the pure osmotic or true capillary forces; above this the rise movement becomes dominant. The second condition of capillary adjustment is the one most commonly found in a natural soil, since a water table a short distance below the surface is not usually contributive to the best crop growth. In studying the rate and height of capillary rise in any soil, however, the maintenance of a supply of free water at the lower end of the column is usually provided for, since this allows a near approach to the maximum capillary capacity for any point in the column.

145. Factors affecting rate and height of capillary movement.—To persons familiar with the habits of growing plants it is evident that capillary movement must play an important part in their nutrition, since the materials are enabled by being their absorbent surfaces in contact with all the interstitial spaces where the bulk of the available water is held. Consequently a consideration of the movement of capillary moisture is necessary, not only as to its mechanism, but also as to the factors influencing its rate and height of movement. These factors are best in number: (1) thickness of water film; (2) surface tension; (3) texture; and (4) structure.

146. Effect of thickness of water film on capillary movement.—It has been repeatedly noticed, in the study of the capillary adjustment between tree soils, that the lower the percentage of water, the slower is the rate

line of the former column. King¹ shows this by the following data:—

Experimental plots and distances in three columns of Experiment 1, showing that there is constant rate of flow.

| Length of column in inches | Distances in inches of water a day |
|----------------------------|------------------------------------|
| 0 | .114 |
| 12 | .111 |
| 18 | .108 |
| 24 | .105 |
| 30 | .102 |

Triggs and Lapham² found, in comparing the excretion from tubes of different lengths (85 and 155 cent.; water, respectively) of *Sua* tubed soil, that the shorter column showed over five times as much excretion in a period of forty-two days. This diminished flow with the denser films is a vital point in plant protection, since wilting must occur as soon as capillary movement becomes too sluggish to supply moisture fast enough for normal development.

The thickness of film is important also in a consideration of the height of rise in dry and moist soil respectively. It is evident that the rate would be much more rapid in the latter, but what up to what rise? Stewart³ is really

¹King, P. E. *Physics and Conditions of the Movement of Ground Water*. U. S. Geol. Sur., 1916 Jan. Dept., Part II, p. 67. 1909-1910.

²Triggs, L. A., and Lapham, M. R. *Caulinary Studies*. O. A. D. A., New York, 1916, p. 24.

³Stewart, G. W., and Lapham, M. R. *Caulinary Studies*. U. S. D. A., New York, 1916, p. 70.

ing the capillary limits as to the height of rise in dry and moist Michigan soils, found this limit much greater where the soil was damp. The vertical rise from a water table was almost five times greater, on the average, in the soil in which the films were originally thicker. Briggs and Laplanche¹ found the rise in the United soil to be as high as four and one-half, while Wesley² has shown that with 9.5 per cent of moisture to raise moisture from a water table one-half higher in six days than did the same soil dry. It is evident, therefore, that a soil with a thick capillary film will carry moisture faster than one with a thinner film, and also will raise the moisture higher when the final film adjustment has taken place.

In an *air-dry* soil it is obvious that before capillary may take place a thicker film than that already existed must be established. This is often difficult because of the presence of oily materials deposited on the surface of the particles during the process of drying out. Such a condition probably accounts, at least partially, for the difference in total rise of capillary water in a dry and in a moist soil, since, essentially, if time enough were given for adjustment, the total height should be the same in both columns. The evidence of dry soil as to the assumption of a capillary film is made use of in soil studies, where a dry surface layer of the soil checks evaporation by impeding capillary rise. It is also obvious that in a study of the rate and height of capillary movement and the factors affecting it, moist columns should be used, as this is a

¹ Briggs, L. J., and Laplanche, M. H. *Capillary Studies*. U. S. D. A., Bur. Soils, Ed., 22 p. 25. 1902.

² Wesley, R. *Untersuchungen über die Kapillare Leitend des Wassers in Boden*. *Reichert & Co. Jahrb. d. Agri-Physik*, Band 7, Seite 119-120. 1858.

one approach to the conditions of a field soil. Since this is rather a difficult study to carry out, most of the soil height data on capillary movement have been largely obtained with dry columns in contact with free water at the bottom. Such data are comparative, but are far less quantitative as regards the performance of any soil under normal conditions.

33. Surface tension and capillary movement. — As has already been shown, the thickness of a maximum capillary film is largely determined by surface tension; and as surface tension with any given substance exerts a definite pressure, it is evident that this pressure may become greater or smaller with variations in the surface tension. One of the most potent factors having to do with this variation is temperature. If the temperature of a soil remains in capillary equilibrium and consistency its maximum capillary moisture should be noted, were it the water would be lost in the water, since the pulling power of the film would be decreased. In the same way, the capillary capacity would be increased by lowering of the temperature, which of course would raise a higher capillary rise in either a dry or a wet soil. The two of movement¹ however, would be facilitated in the first case, since the viscosity of the water would be much reduced, allowing the movement in the film channels to take place with less friction.

King² has verified these conclusions in his experiments

¹ Wöber, H. Untersuchungen über die Capillare Leitung des Wassers im Boden. *Zeits. u. J. Gebiete d. Agr.-Physik*, Vol. 1, 1910, p. 524.

² King, F. E. Phenomena of the Liquid and Gaseous Flow of Ground Water. U. S. D. A., Weather Bur., Bul. 5, pp. 39-40, 1912.

with the fluctuations of the ground water of a soil bed in a large cylindrical tank. He found that with a lowering of temperature the ground water was lowered, due to the increased capillary capacity of the soil generated by a higher surface tension. A consequent upward movement of water took place. When the temperature was raised, however, there was a reverse movement, due to a change of capillary water to free water brought about by a lowered surface tension.

The surface tension may also be varied by material in solution, most salts tending to cause increased tension. The addition of soluble fertilizer salts to a soil would therefore be expected to exert some influence. It must be remembered in this connection that all soils contain a certain amount of oily substances, produced during the processes of organic decay. It is probable that the lowering effect of such material would largely counterbalance any material influence from fertilizer salts. Moreover, as such salts are strongly absorbed by the soil particles, their effect on the concentration of the surface film would probably be slight even if introduced by the soil water. Willey¹ has shown that adsorbed salts produce little effect on capillarity, while nonadsorbed salts cause a depression increasing with concentration.

Rejzys and Laplanche² found that with *Sua edulis* and dissolved salts in dilute solution had no appreciable effect except in the case of sodium carbonate. The increased rise in this case they ascribe to the saprophication of the

¹ Willey, A. Untersuchungen über die Kapillare Leitvermögen. *Monatsh. u. d. Geol. u. Berg. Physik*, Band 7, Seite 297-310, 1884.

² Rejzys, J. R., and Laplanche, M. R. *Capillary Moisture*. D. R. D. A., Res. Rept. Bul. 19, pp. 1-24, 1933.

als on the particles, and a consequent exposure of their surfaces for capillary movement. These actions found also that mineralised solutions reduced the rate of capillary movement. Davis,¹ in working with a silicate, obtained variable results, water salts depressing and some gas-forming capillary rise. Potassium acid phosphate caused the maximum retardation, while ammonium nitrate most markedly increased the rate. Since only one soil was used and the greatest observed capillary rise was less than twelve inches, additional data must be presented before it is clear that the concentration of salts may become a very important factor in humid soils. In arid soils, in which the concentration of the salts is very great, there is no doubt that considerable retardation may occur.

3B. Effect of texture on capillary movement.—In soils of fine texture, not only is the amount of film surface exposed greater than in coarse soils, but the curvature of the film is also greater, due to the smaller radii. The effective pressure exerted by the films is consequently much higher in fine-grained soil. The greater exposure of surface and the increased pressure both serve to make the friction coefficient and retard the rate of flow. The finer the texture of the soil, other factors being equal, the slower is the movement of capillary water. Water should therefore rise less rapidly from a water table through a column of clay than through a sand or a sandy loam.

The height to which water may be drawn by the effective capillary power of a soil, equilibrium being established, depends on the number of interstitial angles. The smaller the number of angles, the greater is the total

¹ Davis, N. O. R. The Effect of Soluble Salts on the Physical Properties of Soils. U. S. D. A. Bur. Soils, Bul. 84, pp. 77-82, 1922.

supporting power of the film. As a silt soil contains a larger number of such capillaries, the capillary pull is greater than that of a sand, and consequently the ultimate movement would be of greater scope. The finer the texture, then, the slower is the rate of capillary movement but the greater is the distance.¹

The relation of texture to rate and height of capillary movement in clay soil is shown by the following unpublished data, obtained in the laboratory of the Department of Soil Technology, Cornell University:

RELATION OF TEXTURE OF SOIL AND HEIGHT OF CAPILLARY RISE FROM A 10 PER CENT SOLUTION OF POTASSIUM CHLORIDE

| Soils | 1 Week | | 2 Weeks | | 3 Weeks | |
|------------|--------|---------|---------|---------|---------|---------|
| | Height | Texture | Height | Texture | Height | Texture |
| Sand . . . | 2.5 | 5.0 | 5.0 | 6.8 | 6.5 | 6.8 |
| Clay . . . | 5 | 27 | 139 | 104 | 122 | 112 |
| Silt . . . | 2.5 | 14.5 | 22.0 | 21.5 | 22.5 | 27.4 |

It is seen that the movement in sand is rapid, one-half of the total rise being obtained in one hour. The maximum height is reached in about three days. The silt in this case seems to be of just about the right textural condition for a fairly rapid rate, yet it exerts enough capillary pull to attain a good distance above the water table. The fluidity in the clay is greater, however, and this results in a slower rate. Whether the clay could ever be able to establish a rise comparable with its permeation pull

¹Wadley, D. *Entwickelungen über die Kapillare Leitung des Wassers im Boden*. French, in: *Annales d'Agronomie*, fasc. 7, 1906, 249-318. 1899. Also, French, in: *Annales d'Agronomie*, fasc. 1, 1906, 319-378. 1905.

ing capacity is doubtful, because of the resistance offered by the dry soil.

III. *Methods and the capillary pull of soils.*— *Antiquities* are applied for measuring quantitatively the capillary pull exerted by a moist soil has been devised by Lynde and Dugel.¹ The apparatus consists of a glass funnel joined to a thick-walled capillary tube by means of a piece of rubber tubing, a water seal being used at this point. The funnel and tube into mercury. The soil to be studied is placed in the funnel, and after being saturated is connected by means of a stick of cinnabar or filter paper to the water column previously established in the capillary tube. If no break occurs between the soil and the capillary water column, the apparatus is ready for use.

The excess water having drained away, there is a thinning of the films on the soil surface due to evaporation. Equilibrium adjustments now take place, which result in the drawing upward of the water column. The aerenity, and the strength of the pull may be measured by the height of the mercury column. The old method of measuring capillary power by the water movement through a dry soil is rendered by two conditions — the length of time necessary, and the fact that the medium will cannot be obtained due to excessive friction. This new method uses a wet soil, requires only a short time, and gives a more ready accurate idea of the power of the capillary pull. It does not, however, point out regarding rate of movement, — a factor of vital importance to plant growth, as will be shown later.

Lynde and Dugel, in their results, confirm the state-

¹ Lynde, C. J., and Dugel, H. A. On a New Method of Measuring the Capillary Pull in Soils. *Ann. Jour. Agron.*, Vol. 6, No. 1, pp. 107-109, 1913.

ments already made regarding the relation of tension to capillary power:

THE CAPILLARY JUMP OF SOIL STRUCTURE AS DETERMINED BY
GRAIN SIZE EFFECT

| Soil | Discrepancy (Osmotic to Molecular) | Jump of Water Column, in Feet |
|--------------------------|---------------------------------------|----------------------------------|
| Medium sand | .5 - .25 | .36 |
| Fine sand | .25 - .10 | 1.76 |
| Very fine sand | .10 - .05 | 4.25 |
| Silt | .05 - .025 | 8.50 |
| Clay | .005- | 26.50 |

The capillary pull may also be established, at least comparatively, by the height of the wetted soil and the amounts of water at various points in a soil column that has reached a capillary equilibrium when its base is in contact with a constant supply of water. The curves from Buckingham¹ (Fig. 34, p. 210) determined after the soil had stood for sixty-eight days, illustrate this.

155. Effect of structure on capillary movement.—Structure has already been shown to affect capillary capacity by its influence on the angle of contact. Evidently, therefore, it may alter both the rate and the height of capillary rise. The loosening of a clay soil or the compacting of a sandy soil will lower the effective resistance, while at the same time it will strengthen the capillary pull resulting in a faster and a higher capillary flow of water. The exact structural condition of any soil in which this result is realized to its highest efficiency it is impossible to judge exactly. In general, however, this

¹ Buckingham, R. *Relation to the Movement of Soil Water*. U. S. D. A., Bur. Soils, Bul. 26, p. 22. 1907.

plant is approached when the soil is in the best physical condition for crop growth. Tillage operations in general, the drainage, and the addition of lime and organic matter, operate toward this result by their granulating tendencies; while tilling, by exposing a few loose straws, may accomplish the same effect but by an opposite process.

At certain seasons of the year regularity must be heeded near the surface, so it continually keeps available water upward to be lost by evaporation. This movement may be checked by protecting on the soil surface, by appropriate tillage, a layer of dry, loose soil. The layer, called a soil mulch, affords much resistance to evaporation because of its dryness, while at the same time it affords but little surface and few night interference for effective capillary pull. Thus it is that a farmer, in order to meet his immediate or future needs, may alter and control capillary movement by careful attention to physical conditions, especially those at the surface where evaporation is always active.

(11) *Constitutional water.*—As soon as the capillary capacity of a soil column is satisfied, further addition of moisture will cause the appearance of free water in the air spaces. By the attraction of gravity, this water moves downward through the soil at a rate varying with soil and climatic conditions. In general the five agencies of free history—pressure, temperature, volume, and movement. In understanding of the operation of these forces is the point, since the rapid elimination of free water from the soil is necessary for optimum plant growth. The actual procedure, however, is undertaken under the head of "Land Drainage," a distinct phase of soil management in itself.

(12) *Pressure and the movement of gravity water.*—It is very evident that any pressure exerted on a water

columns will accelerate the rate of flow. Under normal conditions pressure may arise from two sources, hydrostatic pressure and the weight of the water column. Changes in barometric pressure are communicated to percolating water through a movement of the soil air. As the mercury column rises, more air is forced into the soil and the pressure on the soil water increases. Such a change has been observed by King¹ to produce as high as a 15 per cent decrease in the flow of water. King observed also that the level of wells fluctuated from time to time for the same cause. The expansional force of the soil due to daily heating was also observed to produce diurnal oscillations in the level and the rate of flow of ground water.

Perhaps of greater import in the rate of percolation of water is the pressure produced by the weight of the free water column. Working along this line, Weizsäcker² has shown rather conclusively that with an ideal length of column the flow varies directly with the pressure. His ideal column with the end walls which he experimented was 70 centimeters in length. With a longer column the flow did not increase as fast as the pressure, while with a shorter column, doubling the pressure more than doubled the flow. These results have been verified by Walby³ and fully reviewed by King.⁴

¹ King, P. H., *The Soil*, p. 190. New York, 1900.

² Weizsäcker, D. von, *Experimentelle Untersuchungen über die Durchlässigkeit des Bodens für Wasser*. *Archiv f. Hydrog.*, Band II, Seite 449-512, 1903.

³ Walby, R., *Essai expérimental sur la perméabilité des Roches les Mammes*. *Revue s. s. d. Géologie Appl. Phys.*, Paris 14, série I, 28, 1911.

⁴ King, P. H., *Principles and Conditions of the Movement of Ground Water*. U. S. Geol. Survey, 1906, Am. Geol., Part II, pp. 67-202, 1907-08.

105. Effect of temperature in the flow of gravity water.

—A rise in temperature of the soil not only raises the amount of capillary water and thus increases the possible free water potential, but at the same time it increases the fluidity and thus facilitates percolation. The expansion of the soil air also tends to increase water movement. This can be noticed in the operation of a 6 ft. drain in early spring accompanied with warmer conditions. Calculated effects of temperature change have been verified by controlled experimental results.

106. Effect of texture and structure on the flow of gravity water. — Of much more practical importance than temperature, is the flow of gravitational water, on the size and the arrangement of the soil particles. In working with soils of varying grades, Helanderowicz,¹ Willey,² and others have shown that the flow of water varies with the size of particle, or texture. King³ has demonstrated that in general with such materials the rate of flow is directly proportional to the square of the diameter of the particle. By the use of the effective pore diameter⁴ of a sand sample, he was able to calculate a theoretical flow which compared very closely to observed percolation. In sandy soils this law holds in a very broad way, but in clays it fails entirely. He instance,

¹Helanderowicz, Dr. von. *Experimentelle Untersuchungen über die Durchlässigkeit des Bodens für Wasser*. Zurich, T. Heyman, Band. I, Seite 498-515. 1884.

²Willey, E. *Chemozoologie über das Verhalten der Humus bei Boden für Wasser*. Berlin, W. de Gruyter, 1904.

³King, P. H. *Percolation Conditions of the Movement of Ground Water*. U. S. Geol. Survey, 204 Ann. Rept., Part 1, pp. 225-228. 1907-08.

⁴See text, paragraph 107.

If such a law was in force a sand having a diameter of 5 millimetres would exhibit a flow 10,000 times greater than that through a clay loam with a diameter, say, of .065 millimeter, whereas the actual ratio, as observed experimentally by King, was less than 200.

Evidently, therefore, while it can be stated as a general thesis that the flow varies with the texture, no governing law can be obtained for soils since structure enters with a modifying influence. The percolation is a heavy soil takes place deeply through lines of seepage, which are really large channels developed by various agencies. If in the drainage of average soil, the factors depended on the movement of water through the individual pore spaces, the soil would never be in a condition for crop growth. These lines of seepage are developed by the ordinary forces that function in the production of soil granulation, as freezing and thawing, swelling and drying, time, heating, plant roots, and tillage operations.

A clear understanding of the factors governing the flow of granulation water is of especial importance in the drainage operation, particularly regarding the depth of root interval between the drains. Since percolation is so slow in a heavy soil, it is evident that the tile must be near the surface in order to secure efficient drainage. In a sand the depth may be increased, because of the slight resistance offered to water movement. The depths for laying tile in a heavy soil range from one and a half to two and a half feet, while in a sand the tile may also be placed as deep as four feet below the surface. It is evident also that the less deep a tile drain is laid, the less distance on either side it will be effective in removing the water, consequently on a clay soil the drains must be relatively close, as compared to the interval generally

recommended for a sandy soil. A rational understanding of the movements of gravitation water is clearly necessary in the installation of the drains, not only that the system may be fully effective, but also that a minimum effective cost may be realized.

161. *Determination of the quantity of free water that a soil will hold.*—While there is no particular advantage in finding the quantity of gravitational water that a soil will hold, since a normal soil should never remain saturated for any length of time, it is nevertheless of interest to know by what methods such data may be obtained. One method is to saturate a column of known weight, and then by exposing it to percolation, measure the amount of water that is lost. The gravitational water can then be expressed in terms of dry soil. The disadvantages in this method lies in the fact that it is extremely difficult to free a soil entirely of air, so that a determination made in this way would yield low results. Again, a very long time must elapse before a soil will give up all its gravitational water. King¹ found that with even a soil the desaturation of the free water continued over a space of two and one half years. It must also be noted here that because of the loosening of the capillary water as a column of soil is ascended, the space for possible free water increases, thus accounting for the ready entrance of rain into a soil which on the average may contain a relatively high water content.

162. *The estimation of the free water of a soil.*—A more nearly accurate idea of the possible free-water capacity of soil may be obtained by calculation. If the absolute and the apparent specific gravity of a soil, and

¹ King, F. D. *Physics of Agriculture*, pp. 134-135. Published by the author, Madison, Wisconsin. 1910.

its percentage of moisture when capillary water is known, the following formula may be used:—

$$\left. \begin{array}{l} \text{Percentage of air space when} \\ \text{capillary saturated} \end{array} \right\} = \left(\begin{array}{l} \text{percentage of pore space} \\ - \\ \text{percentage of H}_2\text{O} \\ \times \text{sp. gr.} \end{array} \right)$$

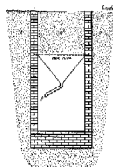
$$\left. \begin{array}{l} \text{Percentage of air under por-} \\ \text{able} \end{array} \right\} = \left(\begin{array}{l} \text{percentage of air space} \\ - \\ \text{sp. gr.} \end{array} \right)$$

133. *Value of studying the soil composition of predrainage water.*—While the determination of the possible free water that a soil will hold is of little real value, a knowledge of its movement and its composition is of vital importance. It has already been shown how the rate of movement of such water is a factor in efficient drainage. The amount likely to be drawn out of the soil in plant production from two standpoints: first, the role that water plays as a food and a regulator; and secondly, the losses of nutrient elements that always come with drainage. It is quite evident that these questions should be studied only on soil in a normal till position. Consequently two methods of procedure are open—the use of an efficient system of the drains, and the construction of lysimeters.

134. *The study of gravity water by means of the drains.*—Is the first method an open should be chosen when the the drain receives only the water from the area in question and where the drainage is efficient. A study of the amounts of flow throughout a term of years will yield much valuable data concerning the factors already discussed. An analysis of the drainage water will show light on the relative losses of plant-food from a normal soil under a known cropping system. The following

of such a method of attack lies not only in the fact that a large area of uncontrolled soil is considered, but also in the opportunity to study practical field treatments in relation to the movement and composition of drainage water.

284. The lysimeter method of studying gravitational water.—The lysimeter method, however, has been the usual mode of attacking these problems. In this method a small block of soil is used, being entirely isolated by appropriate means from the soil surrounding it. Effective and thorough drainage is provided. The advantages of this method are that the variations found in a large field are avoided, the work of carrying on the study is not so great as in a large field, and the experiment is more easily controlled. One of the best-known sets of lysimeters was first established at the Rothamsted Experiment



No. 20.—Cross-section of a lysimeter at the Rothamsted Experiment. Drainage (B) and soil under study (A), and collection layer (C), collect the drainage water.

Station¹ in Maryland. (See Fig. 20.) Here blocks of soil one one-thousandth of an acre in surface area were isolated by means of trenches and tunnels, and, supported in the sections by perforated iron plates, were separated from the surrounding soil by masonry. The blocks of soil were twenty, forty, and sixty inches in depth, respectively. Facilities for catching the drainage were provided under each hydrant. The advantage of such a method of construction lies in the fact that the structural condition of the soil is undisturbed and consequently the data are immediately trustworthy.

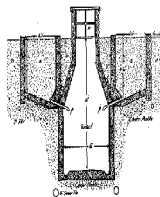


FIG. 20.—Cross section of a soil bank at Cornell University, New York. (a) soil under investigation; (b) method of isolation also.

¹Lawson, J. B., Gilbert, J. H., and Worthington, R. On the Absorption and Compression of the Root and Endosperm Whorls of the Embryo of *Brassica napus*. *Ann. Roy. Agr. Soc. Scot.* 11, Vol. 17, pp. 269-321. 1881.

At Cornell University's system of cement tanks sunk in the ground has been constructed. Each tank is about four and a half feet square and four feet deep. A draining jacket is provided, with a drainage channel opening into a trench beneath and at one side. As the tanks are arranged in two parallel rows, one trench suffices for both (see Fig. 33). The sides of the tanks are treated with asphaltum in order to prevent solution. The soil must of course be placed in the tanks, this causing a disturbance of its structural condition. As a consequence data as to rate of flow and composition of the drainage water are rather variable for the first few years. Such an experiment must necessarily be one of long duration.

106. *Thermal movement of water.*—Little has been said as yet regarding this kind of water movement, the capillary rise, which is not peculiar to one form of soil water but shows all soils. It is at once apparent that the movement of water vapor can be of little importance unless the soil itself, since it depends so largely on the diffusion and convection of the soil air. While the soil air is so closely practically always saturated with water vapor, the loss of moisture by this means is slight. Delehorst¹ has shown that, while sand shows such a movement in the greatest degree, the loss occurring in a soil with any appreciable depth of layer is almost negligible.

The question of the thermal movement of water at the soil surface, however, is vital in farming operations. At this point the water films are exposed to sun and wind, and drying goes on equally, the free capillary, and a

¹Delehorst, T. L. *Zeitschrift für Vergleichende Bodenkunde*, at Cornell University, *Botanische Jahrbücher*, Vol. 20, No. 20, pp. 424-433, 1900.
²Delehorst, T. L. *Zeitschrift für Vergleichende Bodenkunde*, at Cornell University, *Botanische Jahrbücher*, Vol. 20, No. 20, pp. 424-433, 1900.

part of the hygroscopic water depending in the order named. If the loss of the surface moisture were the only consideration, the problem would not be serious; but the capillarity of the soil must be considered also. As the film at the surface becomes thin a capillary movement begins, and if the evaporation is not too rapid a very great loss of water may occur in a short time.

The evaporation from a bare soil in the Rothamsted *lysimeters*¹ averaged about six hundred inches a year, with a rainfall ranging from twenty-five to forty-four inches. This means that from one-third to one-half of the effective rainfall was entirely lost as thermal water. The necessity of checking such a loss becomes apparent, especially in regions where rainfall is slight or drought periods are likely to occur. As no country is free from one or the other of such contingencies, the great importance that methods of modern conservation hold in systems of soil management is indoubtable. While means of checking losses by leaching and runoff are advocated, effective retardation of surface evaporation is always particularly emphasized.

¹Warington, R. *Physical Properties of the Soil*, p. 108. Clarendon Press, Oxford. 1908.

CHAPTER XII

THE WATER OF THE SOIL IN ITS RELATION TO PLANTS

Water, as has already been shown, is one of the external factors in plant growth in that it is necessary in the process of weathering, which results in the simplification of compounds for plant utilization. It also functions as an internal factor in plant development, inasmuch as it maintains the turgidity of the plant cells, acts as a carrier of food materials, functions as a regulator, and can actually be utilized as a source of hydrogen and oxygen. These direct or indirect relations of water to plant growth may be considered under three heads, as follows:—

(I). Relations of water to the plant.—

1. *Water acts as a solvent and a carrier of plant-food materials.* It is therefore a medium of transfer for the mineral and gaseous elements from the soil to their proper places within the plant.
2. *As a food water either becomes a part of the cell without change, or is broken down and its elements are utilized in new compounds.*
3. *Water in excessive supply, in equalizing the temperature by evaporation from the leaves, and in facilitating quick shifts of food from one part of the plant to another, acts as a regulator during assimilation; and while synthetic and metabolic processes are going on.*

Soil moisture, therefore, in proper amounts, becomes one of the controlling factors in crop growth and need, be looked to before the maximum utilization of the primary elements can be expected. The amount of water held within the plant is not large, however, in comparison with the amount lost by transpiration, although green plants contain from 60 to 90 per cent of moisture. Although the water content of the high transpiration of most crops is not amenable to the direct condition of the soil solution, certain regulatory functions may, however, also come into play.

Because of the readiness with which moisture passes from plants into the atmosphere, large quantities of water must be taken from the soil in order that the plant may maintain its proper turgidity. This excess water is largely lost or disposed of by transpiration, at the same time performing its regulatory function.

193. **The water requirement of plants.**—As might be expected, the pounds of water transpired for every pound of dry matter produced in the crop is very large. The figure, called the transpiration ratio, or water requirement, ranges from 300 to 500 for crops in humid regions and almost twice as much for crops in arid climates. An accurate determination of the transpiration ratio of a crop is somewhat difficult, due to the difficulty of providing necessary and also to the difficulty of controlling the numerous factors that may vary the transpiration. For really reliable figures the plants must be grown in cans or pots, in order that the water lost may be determined accurately by weighing. If there is no perspiration, the water certainly lost from a cropped soil includes both that evaporated from the soil surface and that

assumed from the leaves. The former has way be obtained from calculations in two ways: (1) by covering the soil in some way so that evaporation is absolutely checked and the only loss is by transpiration; or (2) by determining the evaporation from a bare pot and, by subtracting this from the total water loss from a cropped soil, finding the loss due to transpiration alone.

In objection to the former method it is that any covering which interferes with evaporation interferes with proper soil aeration also and may render soil conditions abnormal. In the second method, however, an even more serious error arises, since the evaporation from a bare soil is not the same as that from a soil covered by vegetation because of the shading effects. Also, due to the action of the roots, less water is likely to be allowed to reach the surface by capillary attraction in the cropped soil. Therefore, any data that may be gained can be only general in its application, not only because of the errors of determination but also because of the great number of factors that under normal conditions may vary the transpiration rates. The data on the following pages, drawn from various investigations working by the general methods¹ already outlined, give some idea of the water transpired by different crops, due allowance being made for various disturbing factors. Below the data regarding transpiration will be found the directions to the work of the various authors as well as a few notes regarding their experimental procedure.

¹ A brief discussion of the various methods is found in *Methods in Botany*, B. O. Mendenhall, ed. *Determining the Water Requirements of Crops*, Proc. Amer. Soc. Agron., Vol. 3, pp. 265-286, 1911. Also Briggs, L. A. and Shanks, B. L., *The Water Requirements of Plants*, U. S. D. A., Bur. Plant Ind., Bul. 203, 1911.

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WATER UPTAKE OF PLANTS BY DIFFERENT
SOLUBLE SALTS

| Plant | NaCl | KCl | MgCl ₂ | CaCl ₂ | Na ₂ SO ₄ | K ₂ SO ₄ | MgSO ₄ | CaSO ₄ | NaNO ₃ | KNO ₃ | MgNO ₃ | CaNO ₃ | Na ₂ CO ₃ | K ₂ CO ₃ | MgCO ₃ | CaCO ₃ | Na ₂ HPO ₄ | K ₂ HPO ₄ | MgHPO ₄ | CaHPO ₄ | Na ₂ SiO ₃ | K ₂ SiO ₃ | MgSiO ₃ | CaSiO ₃ |
|-------------|------|-----|-------------------|-------------------|---------------------------------|--------------------------------|-------------------|-------------------|-------------------|------------------|-------------------|-------------------|---------------------------------|--------------------------------|-------------------|-------------------|----------------------------------|---------------------------------|--------------------|--------------------|----------------------------------|---------------------------------|--------------------|--------------------|
| Barley | 284 | 171 | 110 | 684 | 488 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Rice | 289 | — | 288 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Barleygrass | 496 | 465 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Oats | 280 | — | 110 | 136 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Yams | — | 225 | — | 171 | 137 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Alfalfa | — | 447 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Oats | — | 465 | 138 | 138 | 488 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Peanut | 220 | 415 | 272 | 477 | 165 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Potatoes | — | — | — | 185 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Yams | — | 812 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Yams | — | — | 338 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |
| Wheat | 247 | — | 338 | — | 144 | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — | — |

¹ Lohr, J. B. Experimental investigation into the amount of water absorbed by plants during their growth. Jour. Hort. Soc. London, Vol. 8, pp. 33-43, 1871.

Plants holding 42 pounds of soil were used. Evaporation from soil was reduced to a very low degree by perforated glass covers mounted on the pots. The figures quoted are from uncalculated soil.

² Wilco, B. Die Wirkung der Phosphorsäure auf die Beschaffenheit und die physikalischen Eigenschaften der Wurzelhaare der Bohnen, Zeits. f. pflanzenk. 1877.

Willow plant plants in summer used in summer ranging from 5 to 10 Volpans. Response was reduced to a very low degree by perforated covers. Actual evaporation from uncalculated soil was observed, however.

³ Hildebrand, H. Beiträge zur des Pflanzenwachstums (Growth of plants), Zeits. f. pflanzenk. 1881.

Willow plant plants in 4 kilograms of soil were used and supplied them with various solutions. The loss by evaporation from uncalculated soil was used in determining loss.

19. *Factors affecting transpiration*.—These figures serve to indicate not only the variation between crops, but also the great effect of climate and soil on transpiration.¹ The factors may be listed under three heads, as follows:—

¹ A complete review of the literature concerning the climatic and soil factors in their effect on transpiration may be found in reference: Pridmore, L. J., and Shantz, H. L., *The Water Requirement of Plants*. T. & G. D. A., Inc., Plant Ind., Bul. 26, 1912.

by transpiration. In later experiments covers were used in order to fix down transpiration.

²Unger, P. H., *Physica of Agriculture*, p. 433. (Published by author, Madison, Wisconsin, 1910. Also, *The Measure of Water Evaporated for a Ton of Dry Matter in Wisconsin*. Wisconsin Agr. Exp. Sta., Bul. Ann. Jour., pp. 246-268, 1908; and *The Importance of the Night Atmosphere and Soil in Relation of Water in Green Production*. Wisconsin Agr. Exp. Sta., Bul. Ann. Jour., pp. 217-224, 1907.

³Also used was holding water (400 pounds of soil). Some were all down into the circle while others were not. Part of the work was carried on in the field; this material was run in vegetable house. Normal soils were used. Temperature here was very low, never being below from January.

The data quoted are the average of a large number of tests.

⁴Lachley, J. W., *Water Requirement of Crops in India, Mexico, Egypt, Iraq, India, China, Korea, Vol. I, No. 4, pp. 120-146, 1911; and No. 2, pp. 225-241, 1911.*

Also evaluating from 12 to 45 thousands of soil from each. Loss by transpiration was determined on how water. The plants were grown in culture houses as in normal conditions.

⁵Unger, L. J., and Shantz, H. L., *Water Requirement of Plants*. T. & G. D. A., Inc., Agr. Jour., Vol. 21, No. 1, pp. 1-45, 1914. Also, *The Water Requirements of Plants*. T. & G. D. A., Inc., Plant Ind., Bul. 26, 1912.

⁶These were grown in a chamber 50 by 50 feet of soil. Evaporation from soil was prevented by means of a porous covering. Water was analyzed in several instances. The data are the average of several years' work.

1. Crops.—Differences due to different crops and to variations of the same crop.
2. Climate.—Rain, humidity, altitude, temperature, and wind.
3. Soil.—Moisture and general fertility.

19. Effect of crop and climate on transpiration.

Not only do different crops show a variation of transpiration in the same season, but the same crop may give a totally different transpiration in different years. This is due in part to inherent differences in the crop itself. For example, leaf surface or root zone would entirely alter the transpiration relationship under any given condition. However, a great deal of the variation observed in the ratios already quoted arises from differences in climatic conditions. As a general thing, the greater the rainfall, the higher is the humidity and the lower is the relative transpiration. This accounts for the high figures obtained by Wilboe¹ in arid Utah. Montgomery² found, in studying the water requirements of corn under greenhouse conditions, that an increase in the percentage humidity from 42 to 65 lowered the transpiration ratio from 540 to 191. In general, temperature, humidity, and wind vary together in their effect on transpiration. That is, the more the radiation, the higher is the temperature, the lower is the humidity, and the

¹Wilboe, J. A. Production of Dry Matter with 100% and Question of Irrigation Water. Utah Agr. Exp. Sta. Bul. 116, 1912. Also *Arizona Investigations: Factors Influencing Transpiration and Transpiration*. Utah Agr. Expt. Sta. Bul. 116, 1910.

²Montgomery, R. G., and Woodcock, T. J. Studies in Water Requirements of Corn. Nebraska Agr. Exp. Sta. Bul. 135, p. 4, 1915.

greater is likely to be the wind velocity. All this would tend to raise the transpiration ratio.

21. *Effect of soil moisture on transpiration.*—From the soil standpoint, however, the factor inherent in the soil itself one of more vital importance is regarded, namely, since they can be considered to a certain extent under field conditions. An increase in the moisture content of a soil usually results in an increased transpiration ratio. The work of Helbig¹ with barley grown in quartz sand containing a nutrient solution may be cited in this regard, together with the data obtained by Montgomery² at Lincoln, Nebraska, with corn grown in a loam soil:—

Summary of Soil Moisture on Transpiration.

| Loam—Montgomery | | Corn—Montgomery | |
|---|---------------------|---|---------------------|
| Soil moisture the average of field capacity | Transpiration Ratio | Soil moisture the average of field capacity | Transpiration Ratio |
| 80 | 577 | 100 | 290 |
| 60 | 560 | 80 | 265 |
| 40 | 216 | 60 | 202 |
| 20 | 223 | 40 | 209 |
| 10 | 198 | 20 | 370 |
| 0 | 195 | | |

These data show clearly that an excessive amount of water in the soil is not a favorable condition for the

¹Helbig, H. Beiträge zu den Bodenverhältnissen während des Wachstums, Seite 139. Braunschweig, 1892.
²Montgomery, R. O. Methods of Measuring the Water Requirement of Crops. Trans. Amer. Soc. Agron., Vol. 8, p. 275, 1911.

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economic use of water, so the plant, in order to supply itself properly with food, must transpire excessive amounts of water. As soil resistance may be controlled, this waste may to a certain extent be eliminated.

175. The influence of fertility on transpiration.—The amount of available plant-food is also concerned in the economic utilization of water. In general the facts along these lines show that the richer the soil, the lower is the transpiration ratio. Therefore a farmer, in making the general fertility of his soil by drainage, lime, and other good manures, borax, potash manures, and fertilizers, provides at the same time for a greater amount of plant production for every unit of water utilized. Again, quoting from Holtinger and Montgomery, the following figures are available:—

EXPERIMENT ON EFFECT OF DIFFERENT METHODS OF SOIL TRANSMISSION RATIO OF WATER CONSUMED IN GROWING AND AVERAGE YIELD OF CEREALS: CEREAL YIELDS IN GALLONS PER ACRE.

| Yield in Gallons per Acre | Soil Water, Depth in Feet for 100 Gallons | Transpiration Ratio |
|---------------------------|---|---------------------|
| 0 | 1.111 | 724 |
| 4 | 0.579 | 386 |
| 8 | 0.308 | 247 |
| 12 | 0.238 | 247 |
| 16 | 0.196 | 232 |
| 20 | 0.160 | 222 |

¹Holtinger, R. Beiträge zu den Naturwissenschaften der Grundlagen der Landwirtschaft, p. 63, Braunschweig, 1883.
²A unit of CaSO₄ is equal to 1 mg. equivalent. A unit equivalent of CaSO₄ is equal to 1 mg.

(Continued) Water Requirements of Crops on Different Types of Minnesota Soils. (EO. Morrison).¹

| Soil | Per. Depth of Root in Cereals (%) | | Transpiration (mm) | |
|-------------------------|-----------------------------------|----------|--------------------|----------|
| | Actual | Expected | Actual | Expected |
| Peat (16 inches) . . . | 170 | 112 | 210 | 540 |
| Medium (50 inches) . . | 110 | 104 | 245 | 675 |
| Heavy (50 inches) . . . | 470 | 270 | 545 | 320 |

128. Effect of surface on transpiration. - The effects of surface have been investigated by a number of men, the work of Van Steenhout² and of Wallace³ being perhaps the most reliable. While these investigators found in general that crops on heavy soils exhibited a lower transpiration rate, hasty conclusions must not be drawn. Since the fine-textured soils contain more plant-food material, it is probable that this is the balancing factor rather than surface alone.

129. Actual amounts of water necessary to mature a crop. - Although it can be seen from the transpiration rate that the amount of water necessary to bring an average crop to maturity is very large, a accurate example may be cited to advantage. A fair estimate of the dry matter produced in raising a forty-day-old crop of wheat would be about two tons. Assuming the transpiration

¹ Henderson, R. G. Water Requirements of Cereals. Minnesota Agr. Exp. Sta. 260 Ann. Rep., p. 21, 1902.

² Steinhilber, C. von. Über den Wasserverbrauch von Weizen, Gerste, Hafer, und Roggen. Ann. L. Landwirtschaftl. Versuchs-Stat. 4, 1868: 192. 1868.

³ Wallace, J. A. Irrigation Investigations. Factors influencing Evaporation and Transpiration. Utah Agr. Exp. Sta. Bul. 105, 1910.

nile to be 300, the amount of water actually used by the plant would amount to 600 times to the acre, or about 52 inches of rainfall. This does not include the evaporation that is continually going on from the soil surface, which might very easily amount to several inches. Moreover, this draft on the soil water is not a uniform one, but increases gradually as the crop develops, until at harvest time great quantities must be supplied in a short period. The necessity of suitable conservation in order to meet the plant requirements and preserve its normal development, even in humid regions, becomes obvious.

174. *Sites of capillarity in the supplying of the plant with water.*—A query arises at this point regarding the mode by which this immense quantity of water is supplied to the plant. The plant roots, especially their absorbing surfaces, are few in number as compared with the interstitial angles that contain most of the water retained in the soil. Then, then, does the plant avail itself of water not in immediate contact with its roots? This question has been anticipated in the discussion concerning the capillary equilibrium which tends to occur in all soils. As soon as the rootlet begins to stretch at one point, the film in that interstitial angle (see Fig. 34) is thinned. A considerable meniscus of the water surface occurs at that point, resulting in a great outward pull which causes the water to move in all directions toward that point. Thus, a feeding center, by absorbing some of the soil solution with which it is in contact, creates a condition of instability which results in considerable film movement. It can therefore be said that capillarity is the important factor in any soil in supplying the plant with proper quantities of moisture.

Many of our early investigators have overestimated

the distance through which this movement may be effective in properly supplying the plant. It must be understood, however, that the rate of water supply is the controlling factor in plant nutrition. It has been shown also that the longer the capillary column, the less is the amount of water delivered from a water table to any given point. Therefore capillary, although it may act through a distance of ten feet, may be important for only three feet so far as plant nutrition is concerned, since water beyond that point is moved too slowly to be of any great value in time of need. No reliable data are available as to this particular phase, but the knowledge of the factors governing capillary movement clearly indicates that capillarity of the soil is of greatest importance in a restricted zone immediately around each absorbing root system.

III. Influence of water on the plant^{1,2}—In general, as the amount of water available to a crop is increased, the vegetative growth also is increased, the plant becoming more succulent. The percentage of moisture in the crop, even at harvest time, is usually high. Quality, practically always suffers with such a stimulation of vegetative activity. This is especially noticeable with such crops as barley and peaches. Stopping qualities also are depressed with increased water, especially if the water available is excessive. With an enlargement of the plant cell a change probably occurs in the cell contents, leading toward a greater susceptibility to disease. Ripening is delayed, coloring is diminished,

¹Wiegman, R. Physical Properties of Soil, p. 156. Oxford, 1910.

²Wienberger, R. A. The Water of Vegetation. *Landw. Jahr.*, Berl. 42, Seite 701-717. 1913.

and the percentage of protein content of the crop is depressed. It is a curious fact, as will be shown later, that many of the general and morphological effects of large quantities of available water on plant growth are the same as those from the presence of too much soluble nitrogen. In some the stimulation of increased water is shown especially in the ratio of grain to straw. Wilson's¹ results in this regard are representative of the data available on this point:—

Decreases in Dry Matter per Acre and Increase in Various Aspects of Water

| Drops in Water | Grain or Percentage of Water, Per Acre |
|----------------|--|
| 4 | 44.6 |
| 7½ | 43.2 |
| 10 | 42.8 |
| 14 | 40.8 |
| 24 | 38.5 |
| 35 | 37.5 |
| 50 | 35.0 |

As a general rule this depression of the ratio of grain to straw is not due to an actual decrease in the grain, but to a correspondingly greater production of dry matter in

¹ Wilson, J. A. The Production of Dry Matter with Different Quantities of Irrigated Water. *Illus. Agr. Exp. Sta., Bul. 111*, p. 48, 1915.

² Fenger, H. Über den Einfluss Verschiedener Boden Wassergaben des Bodens in den Kulturen Vegetationszeiten bei Verschiedenen Nährstoffmengen auf die Ertragsleistung der Kulturpflanzen. *Landw. Anst., Abt. 25, Heft 10*—161, 1901; *Ann. Späcker, G. von, und Förmann, W. Der Einfluss des Wassergabes des Bodens auf die Ernten und die Ausbildung Verschiedener Getreidegewächse. Abt. 1, Landw., Abt. 25, Heft 10*—161, 1901.

the vegetative parts. As available water increases the dry matter increases until a maximum is reached. The general relationships are well exemplified by data from

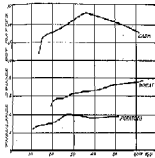


FIG. 40. The effect of increased water supply on the production of dry matter by various crops.

Willow,¹ calculated on the following page, although other equally valuable figures may be obtained from Van Soestren² and Atterberg.³ The curves shown (Fig. 40) illustrate Willson's data and the general trend in the dry matter produced as the moisture is increased.

¹Willson, J. A. "The Protection of Dry Matter with U.S. Forest Reserves of Irrigated Water." *U.S. Dep. Agr. Res.*, Vol. 136, pp. 13-16. 1912.

²Soestren, C. van, and Kuyperveld, Dr. Versuch über den Einfluss, welchen der Wasser in dem Vorhandensein Vegetation auf das Füllen auf sein Wachstum wirkt. *Ann. T. landw. Bond. 46*, Seite 377-379. 1906. Also, Atterberg, A. Die Verhältnisse der Nährstoffgehalte bei dem Absterben von T. landw., *Bund. 46*, Seite 11-13. 1911.

SOIL WATER: PROPERTIES AND MEASUREMENT

DATA GIVEN IN FIGURE 10 ARE GIVEN AS ILLUSTRATION IN
DIFFERENT AMOUNTS OF WATER. WATER

| Depth in Feet | Dist. Between Water | Dist. of Water | Dist. of Water | Dist. of Water | Dist. of Water |
|------------------|---------------------------|----------------------|----------------------|----------------------|----------------------|
| 16.75 | 4.80 | 11.04 | 10.72 | 11.17 | 21.01 |
| 21.50 | 5.45 | 12.54 | 12.10 | 12.67 | 27.00 |
| 22.75 | 5.60 | 13.04 | 12.60 | 13.17 | 28.25 |
| 24.75 | 6.20 | 14.04 | 13.60 | 14.17 | 30.00 |
| 26.75 | 6.80 | 15.04 | 14.60 | 15.17 | 32.00 |
| 28.75 | 7.50 | 16.04 | 15.60 | 16.17 | 34.00 |
| 32.75 | 8.50 | 18.04 | 17.60 | 18.17 | 39.00 |

17. Availability of the water in the soil.—From the discussion already presented regarding the forms of water in the soil, the ways in which they are held, and their movements, it is evident that all the moisture present in a soil is not available for plant growth. Three divisions of the soil water may be made on this basis: unavailable, available, and super-available.

18. Unavailable soil water.—As has been shown in a previous paragraph, free or capillary water may become of little use to a plant through distance, since capillarity is unable to pump the water fast enough to supply ordinary crop needs. Water near at hand or in the immediate zone of the rootlet may also become unavailable through the obstruction of capillarity, friction instead of distance being the cause in this case. As the rootlet thins the interstitial film at any point, capillarity ceases and water moves toward the absorbing surface. This move- ment is rapid enough for plant needs until the film has withdrawn the particles become thin. (See Fig. 37.) As the zone of hygroscopic influence of the particle is approached

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the viscosity increases very rapidly and sets down the capillary to such a point that the needs of the plant are unsatisfied. Wilting therefore occurs simply because the soil is unable to move the water rapidly enough for very needs. As the viscosity of the water increases very rapidly after the point of least viscosity is reached, the wilting coefficient is a figure somewhat less than the percentage representing the least viscosity; i.e., it is greater than the hygroscopic coefficient, since wilting due to viscosity occurs before it is possible for the film to become thinned to the state of hygroscopicity. Not only all the hygroscopic water is unavailable, then, but also a certain small quantity of the capillary water lying between the point of wilting and the hygroscopic film. This relationship is shown by data from the work of Hübner and of Briggs and Shantz, who worked at widely different times and under entirely different conditions.

RELATION OF SOIL WATER FILM TO THE HYGROSCOPIC COEFFICIENT. (HÜBNER.)

| Soil | Water Film | Percentage of Hygroscopic Water |
|--------------------------|------------|---------------------------------|
| Barren sandy soil . . . | 1.5 | 1.15 |
| Barren garden soil . . . | 4.5 | 3.0 |
| For house use soil . . . | 6.5 | 4.10 |
| Barren loam | 7.5 | 5.4 |
| Barren soil | 18 | 12.0 |
| Peat | 46.7 | 32.30 |

¹Hübner, R. Über das Verhalten der Pflanzen des Bodens.
²Water so unsatisfactory. Jahresbericht der Agt. Chem.,
 Band 14, Seite 354-372, 1903.

BALANCE OF TWO WATER PIPES TO THE HYDRAULIC COMPANY.
SUMMARY. *Evaporation and Rainfall*¹

| Item | Evaporation Coefficient | Water Pipe |
|-----------------------------|-------------------------|------------|
| Overhead | 5 | 5 |
| Fire used | 1.5 | 2.8 |
| Fire used | 2.3 | 3.3 |
| Boiler house | 3.3 | 4.8 |
| Boiler house | 4.8 | 6.2 |
| Fire water (iron) | 6.8 | 9.7 |
| Water | 7.8 | 10.2 |
| Water | 8.8 | 12.0 |
| Chlorine | 11.4 | 16.3 |

116. The *wilting coefficient of plants*—It has been known for many years that the various plants possess different capacities for resisting drought. This has usually been ascribed to one or more of three causes: (1) difference in root extension; (2) difference in ability to become adjusted to a slow intake of water; and (3) difference in pulling power against the viscosity of the water film. The last two capabilities would argue for different wilting coefficients for different crops on the same soil. The most extended work on this subject has been by Briggs and Shanks² who found that the permanent wilting point is a constant, wherever it possibly be met for all plants. Later Calkin³ demonstrated that the

¹ Briggs, L. J., and Shanks, R. L. The Wilting Coefficient for Different Plants and its Internal Determination. U. S. D. A., Bur. Plant Indus., Bul. 250, p. 16. 1912.

² Briggs, L. J., and Shanks, R. L. The Wilting Coefficient for Different Plants and its Internal Determination. U. S. D. A., Bur. Plant Indus., Bul. 250, p. 16. 1912.

³ Calkin, J. B. The Relation of Environmental Conditions to the Determination of Permanent Wilting in Plants. Physiological Researches, Ralph H. Robinson. U. S. D. A., Vol. 4, No. 1. July, 1912.

relationship of the physical constants of the soil to the wilting point depends on the rate at which the plant loses water, showing that the soil factors are not entirely dominant in this respect. This work seemed, nevertheless, to indicate that the conclusions of Briggs and Shantz were correct for plants of humid regions, where the wilting occurred in a saturated atmosphere. If such is the case, it can be accounted for only by the fact that the soil forces in their effect on the wilting point are so powerful as to override any distinguishing characteristics that the plants itself may possess, or at least reduce such an influence within the error of actual experimentation.

529. *Determination of the wilting point.*—Briggs and Shantz¹ in their investigations, devised a very accurate method for making determinations of the wilting point. Open tumbler holding about 300 cubic centimeters of soil in an optimum condition were used. The seeds were placed in this soil, after which, not months was passed over the surface in order to stop evaporation, thus ensuring this disturbing factor in the capillary equilibrium of the moisture. The seedlings on germination were able to push through this paraffin. While the plants were developing, the tumbler were kept standing in a constant-temperature vat of water in order to prevent condensation of moisture on the inside of the glass. When definite wilting occurred, as determined in a saturated atmosphere, a moisture test was made on the soil. The resulting figure, within experimental error, represents the wilting point for the soil used.

¹Briggs, J. J. and Shantz, H. L. The Wilting Constant for Different Plants and its Indirect Determination. U. S. D. A., Bur. Plant Indus., Vol. 230, pp. 10-14, 1912.

181. Calculation of the wilting point.—In studying the correlation of this wilting coefficient to soil conditions, Briggs and Shantz¹ advanced the following relationships. Regressed on formula they represent estimates of at least approximating the wilting point from other soil factors. These formulas are arranged in the order of their reliability, based on the data obtained by the authors:—

$$1. \text{ Wilting point} = \frac{\text{Hygroscopic coefficient}}{1.04} \quad (\text{error } 2.8 \text{ per cent})$$

$$2. \text{ Wilting point} = \frac{\text{Hygroscopic coefficient}}{2.8} \quad (\text{error } 7.1 \text{ per cent})$$

$$3. \text{ Wilting point} \\ = \frac{\text{Value found by regressing Wilting method} - 21}{2.9} \quad (\text{error } 3.3 \text{ per cent})$$

182. Relation of texture to the wilting point.—From the data already quoted² from Heinrich and from Briggs and Shantz regarding the hygroscopic coefficient and the wilting point, it is evident that a very close relationship exists between the texture of the soil and the percentage of moisture at which plants wilt. The finer the soil texture, the higher is the wilting point. The following figures, from Briggs and Shantz,³ bring out the point very clearly:—

¹ Briggs, L. J., and Shantz, H. E. The Wilting Coefficient for Different Plants and its Indirect Determination. U. S. G. A., Bur. Plant Indus., Bul. 285, pp. 50-57. 1923.

² This text, paragraph 178.

³ Briggs, L. J., and Shantz, H. E. The Wilting Coefficient for Different Plants and its Indirect Determination. U. S. G. A., Bur. Plant Indus., Bul. 285, pp. 20-23. 1923.

TABLE OF TEMPERATURE VALUES OF VARIOUS TYPES OF SOILS

| No. | Moisture Percentage | Water Power in Horse Power |
|--------------------------|---------------------|----------------------------|
| 1. Soil | 1.55 | .86 |
| 2. Fertilized | 4.00 | 2.00 |
| 3. Fertilized | 5.00 | 2.50 |
| 4. Fertilized | 10.70 | 5.30 |
| 5. Fertilized | 10.70 | 5.30 |
| 6. Fertilized | 10.70 | 5.30 |
| 7. Fertilized | 10.70 | 5.30 |
| 8. Fertilized | 10.70 | 5.30 |
| 9. Fertilized | 10.70 | 5.30 |
| 10. Fertilized | 10.70 | 5.30 |
| 11. Fertilized | 10.70 | 5.30 |
| 12. Fertilized | 10.70 | 5.30 |
| 13. Fertilized | 10.70 | 5.30 |
| 14. Fertilized | 10.70 | 5.30 |
| 15. Fertilized | 10.70 | 5.30 |
| 16. Fertilized | 10.70 | 5.30 |
| 17. Fertilized | 10.70 | 5.30 |
| 18. Fertilized | 10.70 | 5.30 |
| 19. Fertilized | 10.70 | 5.30 |
| 20. Fertilized | 10.70 | 5.30 |

Driggs and Shantz have attempted to express this correlation by a formula which, while very inaccurate, does in general the relationship already expressed. The correlation is this: $\text{moisture} = \frac{\text{water power}}{\text{water power} + 1}$ (where 1 is the water point and the mechanical composition of the soil).

Water point = .01 sand + .02 silt + .03 clay (where 1 is per cent).

333. Available and super-available water.—Advancing from the wilting or critical moisture content of a soil, all the remaining capillary water is found to be available for normal plant use. However, when free water begins to appear, a condition adverse to plant growth is established, and so the saturation point is approached. This condition becomes more adverse. This free water is designated as the super-available water, since it is beyond the available and its presence guarantees conditions unfavorable to plant growth. The upper limit of

the capillary water is called the maximum water content for plant growth. The bad effects of free water on the plant arise largely from the poor aeration that results from its presence. Not only are the roots deprived of their oxygen, but toxic materials tend to accumulate. Favorable bacterial activities, such as nitrification and ammonification, are much retarded also.

The various forms of water in the soil and their availability to the plant are illustrated schematically in the following figure.

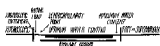


FIG. 45. Diagram showing the forms of water in the soil and their availability to the plant.

184. Optimum moisture for plant growth.—It is very evident that there must be some moisture condition of a soil which is best for plant development. This is usually designated as the optimum content. It is not to be assumed, however, that the total range of the available soil water represents this condition for optimum plant growth. Nor is this optimum water content in any particular soil to be designated by a definite percentage. In reality the moisture in a soil may undergo considerable fluctuation and yet allow the plant to develop normally. This is because the physical condition of the soil changes with varying water content and the plant is able to accommodate itself to such a fluctuation without a disturbance to its normal development, occurring. Willey¹ has shown that the optimum moisture for corn

¹Willey, R. Untersuchung über den Einfluss des Wassergehalts auf den Fruchtentwicklung des Korns.

ness field crops in general covers a range from 10 to 30 per cent of the water capacity of the soil. Mayer¹ placed the optimum moisture content of wheat at 85 per cent of the water capacity of the soil, rice at 75 per cent, barley at 75 per cent, and oats at from 68 to 70 per cent. Such estimates are only approximations; the range of optimum moisture conditions, but at the same time show the relatively high percentage of moisture necessary for maximum crop growth.

Conservation has considerable influence on the range of optimum moisture coefficients, since the better the granulation, the better is the soil able to accumulate itself to changes in water needed without disturbance of plant growth. The poorer the tilth of any soil, the narrower does this fluctuating optimum moisture become. In moisture conservation and control a granular soil is one of the best improvements to be made at. Draining, having addition of organic matter, and tilting, by leading up to such a condition, increase the effectiveness and economy of utilization of soil moisture.

¹Plants. French, A. & Chénier, A. *Agri-Physik*, Band 20, 94a-95-100, 1927.

²Mayer, J. Über das Optimum Minimum und Maximum Wasser von Wasser auf die Intensität der Wasser-Absorption. *Zoon. f. Landw.*, Band 44, Seite 157-164, 1896.

CHAPTER XIII

THE CONTROL OF SOIL MOISTURES

In the discussion of the water requirements of plants, it was apparent that for a normal yield of any crop the amount used by the plant alone was very great, varying from five to ten acre inches according to conditions. Were this the only loss of water, the question of raising crops with given amounts of water would be a simple one. Three factors, however, of water loss, however, are usually found interfering in the soil and tending to lower the water that would go toward transpiration, a loss absolutely necessary for proper plant growth. The factors are: (1) transpiration, (2) runoff over the surface, (3) percolation, and (4) evaporation. The following diagram makes clear their relationships.

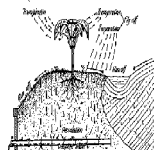


FIG. 13.—Diagram illustrating the ways by which water may be lost from a soil.

It is immediately obvious that as the losses by run-off, leaching, and evaporation increase, the amount of water left for crop utilization decreases. In arid and semiarid regions this is fatal to plant growth, while in humid regions it may be such a factor in periods of drought as to seriously reduce the harvest. Control of moisture is therefore necessary in all regions, and this really consists in so adjusting run-off, leaching, and evaporation as to maintain optimum moisture conditions in the soil at all times. This control should result in a proper and economic utilization of the soil water by the plant.

III. Run-off losses.—In regions of heavy rainfall or in areas where the land is sloping or rather impervious to water, a considerable amount of the moisture received as rain is likely to be lost by running away over the surface. Under such conditions two considerations are important: (1) by not entering the soil the water is lost for plant use; and (2) washing of the soil may occur, which if allowed to proceed may entirely ruin the land. The amount of run-off varies with the rainfall, the slope, and the character of the soil. In some regions it may rise as high as 50 per cent of the rainfall, while in arid regions it is of course very nearly zero. As a general thing, this loss is estimated with the losses by leaching, the two being expressed as one figure.

IV. Percolation losses.—When at any time the amount of rainfall entering a soil becomes greater than the water-holding capacity of the soil, losses by percolation will result. The losses will depend largely on the amount and distribution of the rainfall and the capability of the soil to hold moisture. The best effects of excessive percolation are twofold: (1) the actual loss of water, and (2) the leaching-out of salts that may hinder

to plant-food. The quantity of nutrient elements lost annually from the average soil in a humid region may often equal that withdrawn by the crops. The results from the International drain gauges¹ from 1957 to 1964, on a clay loam soil of these different depths are interesting as to the light that they afford regarding actual drainage losses:—

| | Date P.M. | Drainage measured mm | | | | | Percentage of nutrient leaving surface loss | | | | |
|---------------------|--------------|-------------------------|-------|-------|-------|-------|---|---|---|---|---|
| | | Depth in inches | | | | | Feet | | | | |
| | | 10 | 8 | 6 | 4 | 2 | 10 | 8 | 6 | 4 | 2 |
| January | 2.51 | 1.86 | 3.35 | 1.86 | 78.5 | 84.5 | 93.5 | | | | |
| February | 1.82 | 1.82 | 1.52 | 1.82 | 722 | 810 | 75.5 | | | | |
| March | 1.81 | 0.91 | 1.01 | 0.91 | 475 | 515 | 62.8 | | | | |
| April | 1.89 | 0.56 | 0.57 | 0.52 | 265 | 240 | 24.8 | | | | |
| May | 2.11 | 0.05 | 0.45 | 0.45 | 21.2 | 25.1 | 15.6 | | | | |
| June | 2.25 | 0.02 | 0.05 | 0.02 | 21.9 | 27.9 | 24.3 | | | | |
| July | 2.73 | 0.05 | 0.70 | 0.05 | 25.3 | 24.8 | 23.5 | | | | |
| August | 2.67 | 0.02 | 0.02 | 0.02 | 24.5 | 24.5 | 24.7 | | | | |
| September | 0.70 | 0.05 | 0.05 | 0.05 | 22.8 | 23.9 | 24.8 | | | | |
| October | 3.29 | 1.85 | 1.95 | 1.05 | 217.8 | 212.5 | 22.5 | | | | |
| November | 2.48 | 2.11 | 2.16 | 2.04 | 76.7 | 78.3 | 7.1 | | | | |
| December | 2.72 | 2.22 | 2.25 | 2.61 | 182.3 | 165.9 | 9.8 | | | | |
| Mean total per year | 25.08 | 15.39 | 15.79 | 12.78 | 59.2 | 55.9 | 4.9 | | | | |
| Waters, October to | | | | | | | | | | | |
| March | 14.70 | 10.61 | 10.11 | 10.15 | 66.8 | 72.8 | 0.8 | | | | |
| Summer, April to | | | | | | | | | | | |
| September | 16.38 | 5.01 | 5.67 | 2.64 | 56.0 | 57.4 | 51.1 | | | | |

The rainfall and relative loss through the 45-inch depth of soil is shown graphically in the following diagram:—

¹ HALL, A. E. *The Bank of the International Drainages*, p. 28. London, 1968.

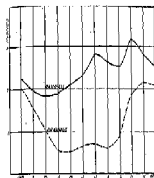


FIG. 45.—Rainfall and percolation losses through a 6-inch soil column. Lancaster records. Deducted Experiment Station, England.

It appears from these figures that about 50 per cent of the rainfall is such a climate as that of England is lost by percolation alone. It appears also that the loss is much lower in summer than in winter, the ratio being about one to three. Also, the longer the soil column, the less is the percolation, due to the greater water-holding capacity possessed by the larger column.

5th. Methods of checking loss by run-off and leaching.

—It must not be inferred that the soil is never in such a condition that percolation, and even run-off, are not advantageous. Often in winter the excess water may be drained over the surface with no damage whatever. Also, when the soil becomes filled with free water, either in winter or in the growing season, drainage must take place in order to establish optimum soil conditions. The control of the free water of the soil may be brought

about by drainage operations or by methods that will increase the water-holding capacity of the soil. The former is really a matter of engineering technique and will be treated in a separate chapter. The latter is a function of the soil itself and must be specifically considered at this point.

The necessity of giving attention to losses due to run-off and leaching varies with climatic conditions. In very humid regions these losses are of great importance, while in arid regions they are insignificant as compared with losses by evaporation. For example, in England the losses by percolation and run-off in some cases are as high as 60 per cent of the rainfall. In the Mississippi River basin the loss is 50 per cent, in the Missouri it is about 24, while in the Great Basin it drops to zero. This does not indicate that drainage is not practised in the last-named region, however, for, owing to over-irrigation, seepage, and other conditions, drainage operations often become as important as in humid climates.

The quantity of water entering a soil is determined almost entirely by the physical condition of the soil. If the soil is loose and open, the water enters readily and little is lost over the surface as run-off. If, on the other hand, the soil is compact, impervious, and hard, most of the rainfall runs away, and not only is there a serious loss of water, but considerable erosion may also result. The first step in checking run-off losses, therefore, is strictly physical in nature. As the water that has entered the soil moves downward it is continually being changed to capillary water in its passage. If the capillary capacity of the soil is high, a greater percentage of this soil water becomes capillary and a less percentage is left to be carried away as gravitational water. The speed in the central

of run-off and percolation, then, is due, to have a loose, open structure of soil in order to facilitate ready entrance of the water; and secondly, to promote and encourage a physical condition of soil which provides high capillary capacity. Drainage, lime, humus, and good tilage encourage granulation, which has so much to do with the proper entrance of water into the soil and its proper handling and utilization therein. The benefits of drainage are felt only when free water, superabundant to plants, becomes present. Its quick removal, therefore, not only better the physical condition of the soil, but also aids in the maintenance of the optimum moisture condition for the plants.

Fall and early spring plowing is always recommended as a means of increasing the moisture capacity of the soil, particularly where organic matter is not supplied.

It provides a deep soil, and should establish the best condition for the storage of moisture, so well as food, for the plant. If organic matter is not supplied, deep plowing is not advisable on light sandy soil; but on dry soil it is beneficial because of the loosening and granulating effect. Fall plowing in particular is to be recommended for such soil, as the loose condition produced facilitates the entrance of surface water while the probability that the soil granulates during the winter increases its water-holding power. A soil in excellent physical condition may contain considerably more water than the soil of the same texture but in poor till, and yet present better conditions for crop growth. Where fall plowing cannot be done, early spring plowing is the next best procedure.

108. *Evaporation losses.*—Evaporation of soil water takes place almost entirely at the surface, exceptions

50. LOSS: EVAPORATION AND MANAGEMENT

being many deep, large cracks occur, which allow thermal loss directly from the subsoil. This loss of water by direct evaporation from the soil may be extensive and may result in direct reduction of the crop yield — a type, at least so familiar that examples hardly need be cited. In the results with the Hetchumet rain gauges about 50 per cent of the annual rainfall was registered in the drainage water. Since the gauges have no crop, the remaining 50 per cent must have been lost by evaporation. It should be noted that in the summer months under warm temperatures this loss was greatest, amounting to 25 per cent of the rainfall. Consequently, in the arid and semi-arid sections of the country, where there is little or no drainage, the rainfall is all lost by evaporation. Investigations indicate that about 70 per cent of the precipitation on the land surface is directed from evaporation from land surface. Even in humid regions, where the annual rainfall is ample for maximum crop production, the crops are frequently reduced below the profit point by prolonged periods of dry weather in the growing season, during which the loss of water from the plants, coupled with the loss from the soil, exhausts the moisture supply.

While run-off and percolation are directly proportional to the rainfall, loss by evaporation does not vary to such a degree. The loss by percolation depends almost directly upon the amount of rainfall above the retentive power of the soil. In years of heavy precipitation losses by percolation must increase. Evaporation from the soil depends largely upon the time that the soil surface is moist, and this will not vary markedly from year to year. The following figures from the Hetchumet disk gauges may be quoted in this regard:—

DROUGHT TEST DOCUMENTS (1919-1921)¹

| Actual Inches | Evaporation Inches | Precipitation Inches |
|---------------|--------------------|----------------------|
| 26.9 | 17.5 | 1.0 |
| 25.5 | 18.6 | 7.8 |
| 26.2 | 18.1 | 11.3 |
| 25.6 | 18.3 | 13.5 |
| 25.6 | 18.0 | 15.0 |
| 25.6 | 18.0 | 16.6 |
| 24.5 | 18.0 | 18.5 |
| 25.8 | 18.2 | 22.5 |
| 48.7 | 27.5 | 25.5 |

A rough calculation may be made which will show the requirements of the yearly rainfall in a broad region of the temperate zone between the three forms of losses—run-off and percolation, evaporation, and transpiration. The precipitation under a rainfall, say, of 20 inches, as shown for the hypothetical year, is roughly 14 inches, or 70 per cent. The water requirement of an ordinary crop is about 7 inches. This leaves a loss of 7 inches to be credited to evaporation. In other words, while the rainfall goes as run-off and percolation, while the other half is divided about equally between the plant and loss by evaporation. While run-off and percolation may be checked to some extent, not enough conservation can occur in this direction to tide a crop over a period of drought. Permanent attention should therefore be directed toward the checking of losses by evaporation, since moisture thus saved means just that amount added to the water available for crop use. It should be remembered that over a large proportion of cultivated lands

¹Warington, R. *Physical Properties of the Soil*, p. 320, 1905.

the crop yields are controlled more directly by lack than by excess of water. It is a common observation that soils which seriously give a low yield in seasons of unusual or low rainfall give good yields in wet seasons, indicating how dominant is the influence of moisture on soil fertility.

108. *Methods of checking evaporation losses.*—All methods for the reduction or elimination of evaporation losses depend on one or both of two functions: (1) the actual control of evaporation as it occurs at the surface, and (2) the prevention of the movement of capillary water upward to take the place of the moisture already lost. It has been shown that as water is lost at the surface of a soil, movement is induced and capillarity is set up. Such action, if allowed to continue, must ultimately bring about great losses. The obstruction of capillarity would obviously lower these losses to a marked degree. As it is difficult and often impracticable to actually eliminate evaporation, the most successful methods of water control usually involve a change in the structural condition of the soil which tends toward a lower capillarity, especially at the surface. Of all the methods of moisture conservation, the use of a mulch has been found most satisfactory. The consideration of mulches is therefore one of the most important phases in the study of moisture control.

109. *Methods for moisture control.*—Any material applied to the surface of a soil primarily to prevent loss by evaporation may be designated as a mulch. It may at the same time fulfill other useful functions, such as the keeping down of weeds and the maintaining of a uniform soil temperature. By the conservation of the moisture, more water remains in the soil for the action

of the essential elements, and bacterial activity is encouraged. As a general rule, more suitable plant-food is likely to be found under a mulched soil, other conditions being equal, than under a soil not so treated.

(3). *Kind of mulches.*—Mulches are of two general sorts, artificial and natural. In the former case, foreign material is merely spread over the soil surface and evaporation is obstructed thereby. Müssen, straw, horse, and fish-lime, may be used successfully. Such mulches, while very effective, are not generally applicable to field crops where intertillage is possible, since they would make cultivation absolutely impossible by covering the soil surface with a large amount of hard material. Their use is therefore limited to intensive crops such as are found in trading operations. Leaves, including pine needles, and sawdust are very effective as a mulch, but some precautions should be observed in their application. For example, the soil is often so hard and, when they are worked out of the mulch into the soil and, by its effect on the growing plant may cause a burning of the soil. In some European countries, as well as in a few localities in America, stones have been thrown on the soil to serve as a mulch, particularly in orchard and vineyard culture, with markedly beneficial effects. Particularly in this case on arid lands as one step to permit cultivation. As further evidence of the utility of this practice, it has been observed in the fruit-growing section of the Ozark Mountains, and elsewhere in other regions, that the removal of stones from the land not only results in the soil's becoming looser, but also makes crop yield by increasing loss of moisture. It is therefore necessary for the farmer to decide whether the immenseness in tillage or other operations due to the presence of

stones may not be more than offset by their beneficial effects.

The materials for mulching mentioned above are, of strictly artificial, and their application is greatly limited, due to the bulk of material and the expense involved. They are therefore used only under special conditions. The recent type of mulch is almost universal in its practical availability.

By proper cultivation almost any soil surface may be brought into such a condition that evaporation of moisture is more rapid than the upward capillary movement. This is because surface tillage produces a loose, open structure, which, while increasing the rate of thermal movement of the water, at the same time obstructs capillary action. The surface layer, therefore, quickly becomes air-dry and is in a condition designated as a soil mulch. As it differs from the soil below only in structure, it has numerous advantages over artificial mulches, at the same time performing successfully all the functions of the latter. Since not only the water in the mulch is scattered but also a small quantity pumped upward by capillarity during the operation, weed formation is of importance. The tillage implements that give the maximum looseness and penetration and prove the most successful. A spike-tooth harrow or a weeder is the instrument ordinarily employed.

394. **The function of a mulch.**—A soil mulch depends for its effectiveness on two functions—(1) the shutting off of evaporation, and (2) the checking of capillary upward movement. It has already been shown that thermal movement of water through dry soil layers is practically nil; therefore, so long as the soil is dry, evaporation is

¹ This text, paragraph 396.

very low. Moreover, any layer of sticky soil remains wetting, principally because of the tension and oils that become deposited on the surface of the soil particles. The material, called "apfrens," has a low surface tension and the capillary water film is not easily removed under such conditions. Again, if the soil is well granulated it is able to assume a looser and more open structure. The interstitial spaces, which afford spaces for capillary surfaces, are cut down, and the capillary pulling power of the layer is much reduced even if it should assume a film of water. It is evident that looseness and drainage are the essentials in the efficiency of a soil under. As long as a match is dry, nature is not a very important factor in efficiency, a dry sand being about as effective as a dry clay. Texture is important, however, in the length of time that a match will remain effective. This is the fact that the capillary power of a clay is so great, it will become moist from below after a few days, while a sand would, if there is no rain, still remain dry for an indefinite period. On a heavy clay and in the fifth a match may be developed by wind, heavy weather, or by a number of days of very humid atmosphere; such a condition, by causing condensation of moisture on the clay, hastens the reestablishment of capillarity with the soil, thus allowing moisture to be pumped up and lost.

286. The soil match versus the dust match. A few words will not be amiss at this point regarding the term "dust match," which is observed so constantly in soil literature. This term would indicate that the match is in a very fine condition, its granules having been broken down. Such a condition would not be conducive to efficiency, as it would encourage capillarity, while at

the same time it would become polluted on rotting — certainly a very undesirable condition. As a matter of fact, efficient matches are not in a short form, but are granulated and much looser than could be obtained were they freely divided. It is evident that the term "dry match" is incorrect and should be superseded by "air match," a figure of speech which more exactly expresses the true field condition.

104. *Formation of a match.*—It has already been stated that a match should be formed as quickly as possible. This would not be such a factor were the match adjusted only once in a season. It is necessary, however, especially in humid regions, to re-form a match every week or two days. The cutting-down of kormelia leaves therefore becomes important. In general the match should be made just as soon after a rain as it is possible to work the land, since the most rapid evaporation occurs during the few hours immediately after a rain, when the soil is very moist. Even after light showers the soil should be quickly cultivated, since the rain has here established a capillary communication with the surface and thus provided for a rapid loss of the water already absorbed by previous work. Under still conditions, where the atmosphere is dry and hot and in fine circulation, the surface soil is quickly dried out after a rain. This drying takes place so rapidly that the capillary film quickly becomes so thin that movement is stopped and no more water is brought to the surface. The soil may be over so hot and compact, but as long as it is kept dry it very effectively conserves the moisture below. The more rapid the loss, the more quickly will the match condition be created, and therefore the less the total loss of water is likely to be. This has been demon-

described by Huntington¹ in some experiments in which soil structure conditions were created at the surface of a capillary column, large-size indices in height. The soil was a fine sandy loam. At first the law of water under the soil conditions was very rapid and controlled that under the humid conditions, but the rate of law was dropped considerably below that of the humid column, and continued to fall behind during the twenty days of the experiment. The difference in this case was due to self-wetting, a very common phenomenon of soil heat soils, particularly those of a heavy character. This self-wetting is often seen in sands in humid regions. The outer layers of a sand pile are always moist, due to the self-wetting tendencies of the surface. The results of Huntington are shown in the following curves:—

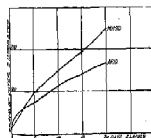


FIG. 42.—Comparison between a sandy loam under humid and self-wetting conditions. Self-wetting has occurred under the self-wetting conditions in comparison herewith.

¹ Huntington, H. Studies on the Movement of Soil Moisture. U. S. D. A., Bur. Soils, Bull. 116, pp. 18-24, 1907.

181. *Depth of a mulch.*—The depth of a mulch is an important question in humid regions. Not only must all the water in the layer be absorbed in order to make the mulch effective, but the plant-food of that layer is consequently withdrawn from use. In humid areas, where the surface soil is usually not over eight or ten inches in depth, the latter consideration is vital, since the fertility of the soil would be greatly decreased by a deep soil mulch. Another factor to be considered here is the possible root prying that may occur while the mulch is being formed. While not of importance early in the season, it is worthy of considerable attention when the intertilled crop remains some days. It has been shown, with such crops as peas, that considerable depression in yield may result from the maintenance of a mulch at a depth of 4 inches, some of the feeding roots being cut off thereby. For such reason the average depth of mulch for humid regions and in dry-farming operations has become regulated to about three inches, although in the late cultivation of corn a less depth than this is maintained. In irrigated regions where little rainfall occurs and where the soil is very deep and uniformly fertile, mulches as deep as ten or twelve inches are sometimes found, especially in orchards. An orchard owner had first tried during the season, with a mulch often weeds no attention except for its original formation. With crops having shallow roots a three-inch mulch is most of course to be used.

182. *Manner of mulch control.*—To summarize briefly, the cardinal points in mulch control are: (1) mulches are more effective and more easily maintained in arid than in a humid climate; (2) their efficiency depends directly on their degree, however, and growth rate; (3) arid soil is more easily maintained as a mulch than clay soil;

(5) from two to three inches is certainly the most effective depth; (6) after a heavy rain, the soil water must be removed by tillage, and this is much more exacting than on sandy soil, even without this, a dry mulch *may become* sufficient; (7) tillage for mulch purposes need, ordinarily be more frequent in spring or during periods of heavy rain, than at other times of the year; (8) the use of foreign materials as mulches may be justified under special circumstances.

127. *Water used by a mulch.*—It is very difficult to grade data regarding the capacity of a mulch to conserve moisture, since conditions vary to such a degree from one region to another. Again, water may not be the limiting factor in crop growth, and even if moisture were used there might be but little influence on crop yields. As a general rule, mulches are most easily maintained and most effective in arid and semiarid regions. Since there is no doubt that moisture, under such conditions, is the limiting factor in plant growth, data from such regions should be especially significant.

MEANEST TEMPERATURES IN WATERSIDE AND GLENDALE, ILLINOIS, MONTHLY AVERAGES IN THREE YEARS.¹ DEGREES F.

| | 1910-11 | 1911-12 |
|-----------------------|---------|---------|
| Wet foot | 15.8 | 10.8 |
| Wood foot | 14.4 | 9.4 |
| Thin foot | 12.2 | 9.5 |
| Barley foot | 9.1 | 8.8 |
| Wheat foot | 9.0 | 8.5 |
| Average | 12.5 | 9.4 |

¹DeKane, H. O. *Moisture and Mulches in Dry Land Agriculture*. Trans. Amer. Soc. Agron., vol. 4, p. 131, 1911.

If the wilting point of this soil is 5 per cent, the available water content must then be at least 3.8 per cent available moisture. This 3.8 per cent of available moisture by which the mulched soil exceeds the available moisture by which the unmulched soil exceeds the available moisture is equivalent to a five-foot depth of about 250 tons of water, enough to increase the crop by a ton of dry matter—certainly not an insignificant saving where crop yield and minimum are so very closely connected.

A considerable amount of experimentation¹ is available which seems to indicate that mulching a soil does not so much fix yield over a soil not so mulched. One reason for this, as already suggested, may be in the fact that water may not have been the limiting factor, the rainfall having been just right in amount and distribution. Again, the roots may have so interpreted the available water as to have altered so some composition from the unmulched soil that from the mulched. In some soils hard layers where from which act in repelling capillary movement. Such a condition would function successfully in checking leeches as if a true match were present. In the study of mulches and their value in increasing a crop, detailed opinions should not be advanced until every phase has been thoroughly investigated regarding the exact factors dominant in the determination of yield. The extended use of soil mulches in the Chesapeake and in dry-farming operations argues for their benefits.

128. Effect of mulches other than on moisture.—That mulching a soil has other effects besides the conserving of moisture is universally evident. In general the physical condition of the soil is always better after a crop than before.

¹Quinn, J. H., and Cox, H. B. *The Weed Factor in the Cultivation of Cereals*. U. S. D. A., Bur. Plant Indus., 1944, 257, 310.

been intertilled. Not only has the surface been kept well granulated, but the presence of optimum moisture below has allowed the granulating agents to become more active. The following of particles by one is, at least partially, an attempt to take advantage of the better side of the soil with a crop that is particularly beautiful climatic. Again, a much not only tends to show a ready entrance of water into the soil, but at the same time increases the water-holding capacity - factors almost emphasized in the discussion of control of losses by penetration and runoff. By leaving these weeds¹ rather saving a chemical, not only to moisture but also in plant-food. Some results from an experiment² conducted at Cornell University serve to illustrate the relation of moisture and weeds to soil moisture and crop production in a humid region in a season of good rainfall. The crop grown was maize. Every 5000 plot was a check and was given normal treatment:-

| | From Corn crop to Corn and Maize Crop Plots | From Maize crop to Corn and Maize Crop Plots |
|---|--|---|
| Check plot | 100 | 51.1 |
| Wheatgrass, but not cultivated | 99 | 82.2 |
| Wheat with straw | 221 | 22.0 |
| Corn plot | 802 | 18.2 |
| Wheatgrass, weeds allowed to grow | 71 | 5.8 |
| Wheatgrass, weeds allowed to grow | 58 | 13.5 |
| Check plot | 801 | 17.7 |

¹Chick, J. S., and Orr, E. R. *The Weed Problem in the Cotton Belt of China*. U. S. D. A. Bur. Plant Indus. Bul. 279. 1915.
²Yang, C. H. *The Effect of Weeds on Maize in North America*. A thesis for the degree of M. S. A., Cornell University. Ithaca, 1924.

The application of a soil mulch is not confined to infertile crops such as maize, potatoes, vineyard, tobacco and the like. Under some conditions it may be applied to grain fields with good results. In those sections of the country where dry farming is prevalent, it is not uncommon to drag the grainfield with a sharp-tooth harrow, the teeth pointing backward. This is begun when the plants are small, and may be continued until they attain a considerable size or until they sufficiently shade the ground to greatly reduce surface evaporation.

226. *General usefulness of a mulch.*—While a soil mulch is used primarily in order to conserve moisture, its *value* likewise varies somewhat in different regions according to climatic and cropping peculiarities. In dry-farming regions mulch is practically necessary to enable the poor rural, more moisture used be saved from the previous summer and winter to the growing season in order to supplement the rainfall occurring at that time. In irrigated regions a mulch is useful in two ways—by conserving the rainfall and by checking the loss of irrigation water; after the latter is once in the soil less additional water need be applied and the consequent cost of irrigation is much less. Again, in arid regions where there is no excess of soluble salts, rapid evaporation is detrimental since these salts tend to concentrate near the surface and become harmful to plants. The prevention of this rise of alkali is therefore a very important function of the soil mulch in such regions.

In humid regions the utilization of a soil mulch is much less intense, even the conservation of moisture over long periods is unnecessary, due to the rainfall. However, during the growing season periods of drought occur, when if available water is lacking in the soil the

crop suffers. The amount of moisture observed by a *nekihi* will usually keep the plant passing seasonally through such periods, while crops on soils not so treated may suffer greatly. The taking of crops over short periods of light rainfall is the chief function of mulches in humid climates.

20. Other practices affecting evaporation losses.—Although the control of water by mulches is such an important consideration, other means of checking losses are available. These may be grouped under five heads: (1) fall and early spring plowing, (2) rolling, (3) sheeters, (4) level cultivators, (5) rills.

21. Fall and early spring plowing. Fall and early spring plowing are much of their efficiency in the conservation of moisture effected through the action of a mulch over the surface. Fall plowing may be practiced for a number of reasons, but its regions of greatest utility, particularly in winter, the conservation of the moisture in the soil at the close of the growing season is an important consideration. This practice is well adapted to those soils in somewhat wetter areas that do not blow too badly when fall-plowed, and where the winter rain is not sufficient to saturate the soil. If the soil is left in the bare, hard condition resulting from the removal of a crop of maize, wheat, or barley, a large quantity of water may be lost by evaporation during the fall months.

For the average farmer in humid regions where the winter rainfall is sufficient to saturate the soil, early spring plowing, coupled with fallows, is very important. Not only may moisture be conserved, but the soil is worked at the stage when it yields most readily to pulverization. Yellow loam, and heavy stable loam of the Delaware soil, are most benefited, some they become

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compact to the very surface is a result of the winter rain and snow, and are therefore in readiness for the most rapid loss of water. They should be plowed as early as practicable without injury to their structure. At the Wisconsin Experiment Station¹ two adjacent pieces of land very uniform in character were plowed seven days apart. At the time when the second plot was plowed, it was found to have lost 17½ inches of water from the surface four feet to the previous seven days, while the piece plowed earlier had actually gained, doubtless by increased capillarity, a slight amount of water over what it had contained when plowed. There was a conservation of easily penetrable water in the soil case as a result of plowing one week earlier—enough to produce 1500 pounds of dry matter in corn to the acre, if properly utilized.

325. *Rolling*.—Very often in the spring, when the seed bed is very loose, rolling is resorted to, in order to bring about a compaction of the soil. At the same time capillarity is established with the firmer subsoil beneath, and as the moisture moves upward a rapid penetration of the seed is induced. Care must be taken that this capillarity be checked once it has performed this office, so great losses from evaporation may occur at the surface and the crop be killed of much available water. It is an economic procedure in such cases to follow the roller after a few days with a harrow, so that a mulch may be established and this loss checked.

326. *Shedding*.—Shedding of any kind, whether natural or artificial, tends to break the wind velocity and thereby check losses by evaporation. Strips of timber are com-

¹ *Illag. P. II, The Soil*, p. 168. New York, 1915.

mainly proved or related for this purpose. Wooden fences and walls of one sort or another have a similar effect. Windbreaks composed of growing plants have the advantage that for a considerable distance beyond the spread of their branches their roots penetrate the soil and use the moisture, which is one reason for the smaller growth of crops near them. Relying on the efficiency of windbreaks, results by King¹ show that, when the rate of evaporation at twenty, forty, and sixty feet to the breast of a black oak grove fitted to twenty feet high was 11.5, 11.6, and 11.9 cubic centimeters, respectively, that a wet surface of twenty-seven square inches, the evaporation was 14.5, 14.2, and 14.7 cubic centimeters, at two hundred and eighty, three hundred, and three hundred and twenty feet distance—or 24 per cent greater at the outer distance than at the other ones. A sandy bog-grove reduced evaporation 50 per cent at twenty feet and 7 per cent at one hundred and fifty feet, below the evaporation at three hundred feet from the bog.

Very many test devices are used in the proving of screens. The most exact form of the test is a frame eight or nine feet high, over which is spread a loosely woven cloth. Investigation by Skovs² in Copenhagen showed: (1) That the test greatly reduced the velocity of the wind. This reduction amounted to 80 per cent when the outside velocity was seven miles an hour, and 56 per cent when the outside velocity was twenty miles an hour, there being a small regular decrease in relative efficiency with increased velocity of the wind. (2) The relative humidity under the test was higher than outside,

¹ King, P. H. The Soil, p. 205. New York, 1904.

² Skovs, J. B. *Studies of Shading on Soil Conditions*. U. S. D. A., Bur. Soils, Bul. 33. 1907.

and during a good part of the time attained a difference of 10 per cent. The effect of this was to reduce evaporation by from 52 to 65 per cent, on different days in July, in spite of a higher temperature inside the tent. (3) The direct effect of this was to increase the moisture content in the soil in spite of a larger crop growth under the tent. These differences are shown by the following curves (see Fig. 45), which represent the percentage of water in the soil to a depth of nine inches from June 13 to August 1.

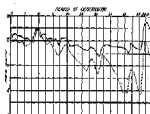


FIG. 45. Curves showing the percentage of moisture in a sandy soil to the depth of nine inches inside and outside of a heavily manured tent kept in place at about 85° days. Heavy line, moisture inside of tent; broken line, moisture curve of soil outside of tent.

Not only was the tent effective in preventing evaporation and thereby increasing the average moisture content of the soil, but the soil was able to maintain a normal flow content, due to the free movement and adjustment of the capillary water under the tent—something most exclusive to rapid crop growth.

594. *Level cultivation.*—The velocity of the wind next to the ground may be checked by rigging the soil. It is doubtful whether this practice increases moisture

because a greater amount of surface is exposed over which evaporation may take place. On the other hand, ridge experiments, as well as theodolite, indicate that, by the conservation of water, level culture is better than ridge culture. This principle has led to the gradual abandonment of the practice of "laying by" even wet patches with a high ridge. In all regions of deficient rainfall, the best practice practices level tillage and a few dry months, such of which are sustained by the frequent use of shallow-rooting small-grain cultivations. Many experiments have demonstrated the larger crop yields to be obtained, on the average, from this practice.

256. *Flants*.—Flants growing on the soil tend to check evaporation from two causes—(1) their shading effect, and (2) the tendency of the roots to intercept capillary water as it moves upward and to appropriate it for plant growth. Flants, however, tend to intercept a certain amount of rain and prevent its over reaching the soil. The amount of water needed in this way by flants ranges from 15 to 20 per cent. To control this tendency just about offsets the saving that comes from shading.

257. *Summary of moisture control*.—It is clearly seen from the discussion of moisture control that the structural condition of the soil is the secret of successful operation. Run-off and leaching are reduced by increased capillary capacity, a structural relationship. Evaporation is checked by a soil mulch, which depends for its effective ness on its physical condition. Drainage, loss, addition of organic matter, and tillage in perfecting granulation function in increasing the ease and effectiveness with which soil moisture may be controlled. It must be only kept in mind that all such control is directed

toward the regulation of the soil moisture is such a way that an optimum water supply may be held constantly in the soil during the growing season. If this can be accomplished, the highest crop yields may be expected that are possible under the existing fertility conditions of any soil.

CHAPTER XIV

SOIL HEAT¹

However, plant growth is practically suspended below a temperature of about 9°F ., while proper germination of seeds does not proceed much below that temperature. As a rule it is not desirable to place either seeds or plants in a soil in which active growth does not take place almost instantaneously, since certain roots and fungi, active at low temperatures, may sap their vitality and ultimately cause their destruction. The desirable chemical reactions in the soil are checked to a certain extent by lack of heat, while the important biological activities are greatly impaired, if not brought entirely to a standstill, when the soil temperature approaches 32°F . Such functions as the decay and putrefaction of organic matter, the formation of ammonia from simple humic bodies, the building up of the humus into the nitrate form, and the fixation of the free nitrogen either by free-living or symbiotic bacteria, depend on an optimum soil temperature.

A knowledge of the functions of heat, therefore, especially as to its relationship to plant growth and bacterial activities, becomes important, for the farmer can by a certain extent control soil temperature. He is able

¹For bibliography of the literature of soil heat, see Thompson, E. J., An Investigation of Soil Temperatures and Some of the Heat-Insulating Factors Influencing It, Michigan Agr. Exp. Sta., Technical Bull. 37, pp. 186-193, 1913.

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also to govern the time when the sowing and planting are performed in such a way that the soil will be fitted, at least as far as is concerned, for proper seed germination and plant growth.

207. Relation of heat to germination and growth.
In order to show the exact relationship of heat to germination of seeds and to the growth of plants, the following data from Hildebrand's¹ are given. While these tables are not exact, they show clearly the necessity of careful control of temperature in the propagation of plants:—

THE RELATION OF TEMPERATURE TO THE GERMINATION OF CERTAIN SEEDS (IN DEGREES FAHRENHEIT)

| | Minimum | Optimum | Maximum |
|------------------------|---------|---------|---------|
| Corn | 40 | 55 | 115 |
| Hardend bean | 45 | 55 | 115 |
| Peas | 50 | 55 | 115 |
| Wheat | 45 | 60 | 100 |
| Potato | 45 | 60 | 100 |

THE RELATION OF TEMPERATURE TO THE GROWTH OF CERTAIN PLANTS (IN DEGREES FAHRENHEIT)

| | Minimum | Optimum | Maximum |
|------------------------|---------|---------|---------|
| Wheat | 35-40 | 75-85 | 85-95 |
| Potato | 45-50 | 75-85 | 85-95 |
| Corn | 45-50 | 85-95 | 95-105 |
| Peas | 50-55 | 75-85 | 85-95 |
| Hardend bean | 55-60 | 75-85 | 85-95 |
| Maize | 70-75 | 85-95 | 115-125 |
| Pumpkin | 75-80 | 85-95 | 115-125 |

¹Hildebrandt, F. Die Wärme und Kälteverhältnisse gewisser für die Vermehrung der wichtigsten Landwirtschafskulturen. Landw. Versuchs. Stat., Band 17, Seite 114-115 1891.

It is noticeable that there are here three groups of plants as far as temperature conditions for optimum growth are concerned. Wheat represents the crops that germinate and grow at a relatively low temperature. Corn requires a medium high temperature for proper growth, while melons and pumpkins represent crops the temperature requirements of which are very high. These needs must be supplied for a proper development of such plants, and must of course be considered in crop adaptation as well as in soil management, in general.

88. *Chemical and physical changes due to heat.*—In the soil a certain amount of chemical action is going on, no matter what the temperature may be; but it is well-nigh certain that this activity is greatly accelerated by an increase in soil heat. This arises from two causes: (1) because heat increases the solubility of the soil constituents; and (2) because the activity of the soil organisms is stimulated to such an extent as to in its turn influence chemical reaction. The increased production of carbon dioxide is a good example of this relationship. The warming of the soil in spring and summer, therefore, by stimulating the natural rate of solution, increases to a marked extent the elements available for plant growth.

The effect of temperature is less marked in a direct way on the structure of the soil than on its chemical or biological nature unless the freezing point is reached. At this point, if moisture is present, the soil mass is disrupted and may become rather granulated if the freezing process is often repeated. The practice of fall plowing works to better the tilth of the soil is really taking advantage of this natural phenomenon. A change in temperature also causes the expansion or contraction of the

soil pores and may greatly facilitate their movement. This is essentially a physical relationship. It must be kept in mind, however, that with heat as with other soil factors, no clear-cut and distinct division of its effects in one direction may be made without considering the indirect influences that are continually operating to increase water heat to places more or less foreign to the one under discussion. This serves to emphasize the close connection of the various factors and conditions that must be dealt with in a study of soils.

300. Sources of soil heat.—The soil may receive heat directly or indirectly from three general sources: (1) from the sun, (2) from the stars, and (3) by conduction from the heated interior of the earth. The two last-named sources are so unimportant as to warrant no further discussion, since the amount of heat received by the soil therefrom is so small as to be negligible.

The sun, then, either directly or indirectly supplies all the heat and energy that make it possible for soils to support vegetation. This heat is derived in various ways, as follows:—

(1) By direct radiation of rays, both of light and of invisible heat. These rays when absorbed tend to raise the temperature of the absorbing medium. This source of heat is by far the most important and may be designated as the direct method of heat radiation.

(2) A considerable amount of heat may be derived by reflection and conduction from the atmosphere surrounding the earth. This heat has at times been originally obtained from the sun and is passed on to the soil, the length of the waves being somewhat changed in the transmission. Clouds may sometimes serve as a blanket and that

is around the earth heat that would otherwise be entirely lost so far as the soil is concerned.

(3) A certain amount of heat may be brought to the soil by precipitation. A warm spring rain, by falling on the earth and penetrating into its surface, may be a determining factor in crop growth. Although the aggregate amount of heat added in this way is small, the opportunities of its application is of no small importance. A warm rain often imparts an impetus to plant growth which may be noticeable for many weeks afterward.

(4) A large amount of heat is annually entraped by growing plants. This energy is stored up and may ultimately be liberated by the decay of the tissue. If such oxidation takes place in the soil, as it very largely should under good farm management, a certain amount of heat is liberating in the soil. How important this is it is difficult to say, for such energy is given off so gradually as to be rendered difficult of measurement. Root activity is very closely allied to the utilization of such heat. There is considerable evidence, as in lettuce on very heavily manured lands, that heat has no appreciable effect in altering the temperature of a normal soil.

330. Factors affecting soil temperature. The temperature that the soil of any given locality may attain is dependent on a certain group of factors so closely related as to make their separate consideration sometimes rather difficult. For convenience these factors may be listed as follows, the actual temperatures and their probable fluctuations under field conditions being reserved until the various intrinsic and external factors of soil heat have been discussed:—

1. Specific heat.
2. Absorption.
3. Diffusion.
4. Conductivity and convection.
5. Retention of moisture.
6. Organic decay.
7. Slope.
8. Heat supply and its effects.

111. *Specific heat.*—The specific heat of any material may be defined as its thermal capacity as compared with that of water. It is the ratio of the quantity of heat required to raise the temperature of a given weight of the substance one degree Centigrade to the quantity needed to change an equal weight of water from 32°F. to 212°F. temperature. A knowledge of the specific heat of soil is important because of the general light it casts on the warming-up of a soil in spring and on the rate of cooling in autumn. The data from a number of investigations, in the order of their priority, is here quoted, the calculations being based on dry soil:—

WATER BECAME: *Heat or Soil.*

| | Plancher ¹ (1881) | Liebschütz ² (1876) |
|------------------------|------------------------------|--------------------------------|
| Fine sand | 1023 | Gravel soil 1831 |
| Aluvial soil | 2547 | Gravel soil 2250 |
| Gravel soil | 3439 | Fine loam 2178 |
| Humus soil | 4163 | Humus loam 2636 |
| Peat | 5089 | Gravel soil 3360 |

¹ Plancher, L. *Ueber die Wärme Capacität Verschiedener Substanzen, und deren Einfluss auf die Pflanz.* Ann. d. Physik u. Chemie, Band 26, Seite 105-115, Leipzig, 1881.

² Liebschütz, B. von. *San Lutz, G. Ueber Wärme Capacität der Bodenmassen.* Preuss. u. d. Grönitz d. Anst. Physik, Band I, Seite 191. 1876.

| Loca ¹ (1979) | Point ² (1929) |
|---------------------------|---------------------------|
| Coarse sand . . . 1980 | Nordak sand . . . 1948 |
| Limestone soil . . . 2020 | Estadok fine sandy |
| Heavy soil . . . 2570 | loam . . . 1828 |
| Garden soil . . . 2970 | Flagerstrom loam 1944 |
| Peat 2970 | Loonathorn loam 1944 |
| | Calveston clay . . 2187 |

| Roggenwald (1959) | |
|-------------------|------|
| Sand | 1929 |
| Gravel | 2045 |
| Clay | 2060 |
| Loam | 2154 |
| Peat | 2528 |

212. Variation of specific heat. — These figures show a considerable amount of variation, part of which is of course due (1) to inaccuracies in the designation of the materials used, (2) to differences in methods, and (3) to differences in technique. Allowing for these possible errors, there still seem to be other factors involved. One of these might be texture, since, according to the earlier investigators, the finer mineral soils seem to possess a higher specific heat. The data of Thompson and Tutton, however, seem to contradict this assumption. An investigation more to the point is that of Ulrich.³ In work

¹Lang, C. *Die Wärme Capacität der Bodenmaterialien*. Munich, u. d. Göttinger u. Agric.-Physik. Band 1, Seite 35-47. 1878.

²Palmer, R. H. *Heat Transference in Soils*. U. S. D. A., Bur. Soils, Div. 53, p. 24. 1899.

³Roggenwald, G. A. *An Investigation of Soil Temperature*. Mimeo. Agr. Res. Sta., Feb. 1951, 17 p. 13. 1953.

⁴Ulrich, E. *Untersuchungen über die Wärmekapazität der Bodenmaterialien*. Munich, u. d. Göttinger u. Agric.-Physik, Band 21, Seite 1-31. 1894.

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ing with various grades of quartz sand he obtained practically identical specific heats with the various samples:—

GRANITE LITER OF VARIOUS GRADES OF SAND AT POINT 10
Kilograms

| Distance of Sand to Millimeter | Specific Heat |
|--------------------------------|---------------|
| 2-1 | .8515 |
| 1-5 | .8508 |
| 5-25 | .8522 |
| 25-171 | .8519 |
| .171-.114 | .8500 |
| .114-.071 | .8506 |
| .071-.010 | .8500 |

It is evident, therefore, not only that texture has no very great direct effect on specific heat, but also that the controlling factor in the data already quoted is the composition of the soil. The predominance minerals found in soils possess a specific heat of from .800 to .200. This rather narrow range would normally be still further lessened, since an average soil is a complex of the different minerals. Humus, then, possessing a specific heat of about .5 unit, when added to any soil, increases materially its thermal capacity and would undoubtedly be the determining factor in weight specific heat of the mixture.

213. *Specific heat based on volume of soil.*—Under normal conditions, however, the soil contains a considerable amount of pore space, and different soils would

¹Thick, R. Untersuchungen über die Wärmeausdehnung der Bodensubstanzen. *Monat. u. d. Abh. d. Agt. Physol.* Band 17, 1906, 1-21. 1904.

therefore show different weights to the cubic foot. A specific heat comparison based on weight, therefore, does not yield a fair idea of the heat capacities of two soils. The multiplication of the weight specific heat by the apparent specific gravity of the soil in question will obviously yield a volume specific heat, which is a much more practical basis for comparison. A quotation from Ulrich¹ makes clear the value of such a comparison:

SEVERAL KINDS OF SOILS COMPARED BY WEIGHT AND BY VOLUME OF SOIL.

| | Specific Heat per Cubic Foot | Specific Heat of Water | Specific Heat of Soil |
|------------------|------------------------------------|---------------------------|--------------------------|
| Loam | 1.35 | 1990 | 2700 |
| Clay | 1.68 | 2550 | 2832 |
| Gravel | .27 | 4515 | 1233 |

It is evident that in the first case the specific heat is governed by the organic content of the soils in question; the greater the amount of organic material present, the higher is the thermal capacity. Such is not the case when the specific heat of the soil is calculated on a volume basis. In an expression of the thermal capacity on this rational basis, namely, that of volume, the apparent specific gravity, or volume weight, is the dominant factor. The addition of humus when this method of expression is employed merely serves to lower the volume weight, and

¹Ulrich, B. Untersuchungen über die Wärmeausbreitung der Feldagarsubstraten. *Zeitsch. f. d. Länd. u. Agrikultur*, Band 17, Seite 121. 1906.

a reduction of specific heat thereby occurs. Under such conditions more heat is necessary to raise the temperature of the soil than in the case with the weight expressed. This is because of its high apparent specific gravity. The clay shows very little change, as its apparent specific gravity is about one; but the loam exhibits a marked falling-off, due to its considerably low volume weight. The factor that tends to vary the specific heat of dry soil under natural conditions, therefore, is the apparent specific gravity, or the volume weight. By deep and efficient plowing the farmer may encourage the warming of his soil, due to a lowered thermal capacity. By increasing its loam content he may attain the same result, since the volume weight is depressed to a markedly greater extent than the specific heat is increased by the addition of organic matter. In fact, any operation on or any addition to the soil that will vary its apparent specific gravity will in turn affect the specific heat.

234. Effect of water on specific heat.—One other factor, much more potent than the two already mentioned, is yet to be discussed. This factor is water, so universally present in soils and of the greatest importance in all natural soil phenomena. As the specific heat of water is very high compared with the thermal capacity of the soil constituents, any addition of it must naturally raise the specific heat of a normal soil. That moisture, not apparent specific gravity nor organic content, is the controlling factor is demonstrated from the following data, calculated by Ulrich¹ on a volume basis:—

¹Ulrich, B. Untersuchungen über die Wärmekapazität der Bodenbestandteile. *Monat. u. d. Göt. u. Agr. Physik.*, Band 17, Seite 27. 1894.

FIG. 35.—THE EFFECT OF THE CHARACTER OF THE WAVE ON THE MEASUREMENT OF THE SPECIFIC HEAT OF THE TOTAL WAVE CHARACTER.

| Wave | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 |
|------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|
| Wave | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 |
| Wave | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 |

It is at once evident, from these data and the accompanying curves (see Fig. 36), that moisture, in its effect on the specific heat of an average soil, is so potent, as to

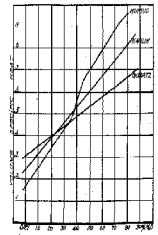


FIG. 36.—Curves showing the effect of moisture on the specific heat of soil of different textures and humidities.

entirely obvious in most cases the variations due directly to such factors as apparent specific gravity and human content. Organic matter, because of its high water capacity, usually necessitates the allowance of moisture in this respect. While a heavy soil of low volume might seem to retain more water, its high water content may increase its thermal capacity so as to markedly retard its temperature changes. This is exemplified by Terri¹ and Boynton² in their study of frost penetration in soil. This soil was the best to freeze in winter and, conversely, the best to thaw in spring. The advantage of retaining excess water by drainage is of importance here for this reason, as a wet soil is normally a colder soil in spring than one that is well drained. This at least partially accounts for the fact that a sandy soil is usually an early one, and is therefore of particular value in trucking operations.

23. Absorptive power of soils for heat. The greater proportion of the heat received by the soil is obtained by direct radiation from the sun. This radiant heat is projected by free wave action in the ether, the space intervening between the sun and the earth being but little affected by the transfer. Were the total amount of heat received from a vertical sun by any unit surface wholly absorbed by a layer of soil twelve inches thick, the temperature of the soil would rise thirty degrees Fahrenheit an hour. Such is not the case under normal

¹Terri, A. Untersuchungen über den Einfluss des Bodens auf die Temperaturverhältnisse der Boden von Versuchslocher. *Zeitschrift für landwirtschaftliche Technik*, 1. Jahrg. 4. April-Heft, Band 10, S. 245-250, 1900.

²Boynton, G. J. An investigation of Soil Temperatures. *Michigan Agr. Exp. Sta., Tech. Bul. 17*, p. 214, 1912.

conditions, however, as the atmosphere continuously reflects, refracts, and absorbs a certain amount of this radiant energy. More important still are certain inherent qualities of the soil itself which function naturally in the modification of the amount of heat absorbed. These factors include color, reflection, texture, and structure.

116. Effect of color on absorption of heat. (See Fig. 55.)—Is a natural soil it is very difficult to effect a change in soil color without changing the texture, structure, and more particularly the constitution, of the particles. In order to eliminate these disturbing factors in a study of heat, a quartz sand colored with various dyes was used by Bouquard.¹ The following data, taken at Lansing, Michigan, on a clear, warm day in August, illustrate the general effects of color on absorption:—

RECORD OF SURFACE TEMPERATURES OF HEAT ABSORPTION AT QUINCY PARK, ANSONIA 5, 120 YAC.

| Color | Temperature (Fahrenheit) |
|------------------|-----------------------------|
| Black | 29.1 |
| Blue | 30.7 |
| Red | 35.3 |
| Green | 34.7 |
| Yellow | 33.6 |
| White | 32.7 |

It is quite evident that the darker the soil, the greater is its absorptive power. This is because of differences in reflection, a light-colored soil reflecting more of the heat rays than one of a darker color. There might be a question here as to the difference in radiative ability from

¹Deppenne, G. J. An Investigation of Soil Temperature. *Michigan Agr. Expt. Sta., Tech. Bul. 77*, p. 23, 1913.

color, the white soils radiating more heat than the black ones. The following data from Bouyoucos,¹ substantiating those of Long,² are a conclusive negative answer to such a query:—

ABSORPTION OF INFRARED-RADIATION FACTS, WHITE SOILS
PERCENT OF 100

| | |
|------------------|-------|
| White | 1,000 |
| Black | 1,071 |
| Blue | 1,041 |
| Green | 1,044 |
| Brd. | 1,044 |
| Yellow | 1,099 |

The addition of organic matter, provided the decay has been of the proper sort, will consequently always raise the soil temperature, other factors of course being equal. Walling³ in experimentation with soils covered with thin layers of different-colored material, found marked differences under field conditions. The black soil not only exhibited the highest temperature, but also showed a greater amount of fluctuation. The minimum temperatures of the different-colored soils were almost the same. The temperature differences of course decreased with depth. Some typical data obtained on a clear day, as quoted from Walling's work, are as follows:—

¹Bouyoucos, B. J. *An Investigation of Soil Temperatures*. Michigan Agr. Exp. Sta., Tech. Bul. 17, p. 30. 1923.
²Long, C. *Über Wärmestrahlung und Erwärmung des Bodens*. *Forsch. u. d. Gebiete d. Appl-Physik*, Band 2, S. 325-327. 1920.

³Walling, B. *Vorlesungen über das Verhalten der Erde bei Strahlung und dessen Bestimmung*. *Forsch. u. d. Geb. d. Appl-Physik*, Band 1, S. 45-48. 1917. Also, *Untersuchungen über das Verhalten der Erde bei Boden- und Lufteinstrahlung*. *Forsch. u. d. Geb. d. Appl-Physik*, Band IV, S. 327-343. 1925.

TABLE 1. — Temperature of the air at a depth of 4 inches, from June 22, 1954, at Moscow (in degrees Fahrenheit).

| Time | At | At | At |
|------------|------|------|------|
| 6:00 a.m. | 91 | 11.5 | 13.8 |
| 7:00 a.m. | 90.0 | 12.4 | 12.4 |
| 8:00 a.m. | 79.8 | 10.7 | 10.8 |
| 9:00 a.m. | 78.0 | 9.8 | 9.8 |
| 10:00 a.m. | 75.8 | 10.4 | 10.3 |
| 11:00 a.m. | 70.8 | 11.7 | 12.8 |
| 12:00 p.m. | 70.8 | 10.1 | 11.6 |
| 1:00 p.m. | 70.6 | 10.3 | 11.3 |
| 2:00 p.m. | 74.8 | 10.4 | 10.6 |
| 3:00 p.m. | 72.0 | 10.8 | 10.8 |
| 4:00 p.m. | 70.6 | 10.2 | 10.6 |
| 5:00 p.m. | 70.3 | 10.1 | 10.4 |

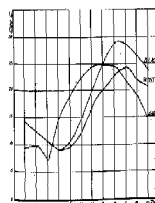


FIG. 1. — Graph showing the temperature variation of different water bodies from June 22, 1954, at Moscow (in degrees Fahrenheit).

Besides the quite obvious effect of the dark color on the rate of heat absorption, two other points are worthy of notice. The first is the tendency of the soil temperature to lag behind the temperature of the air, and the second is the almost equal minimum reached by the two soils. The latter point would seem to indicate also that color had little differential effect on the heat lost from the soil by radiation into the air.

III. Effects of texture and structure on heat absorption.—Undoubtedly the texture and the structure of a soil, other conditions being equal, have little direct influence on rate of absorption. Walling¹ found acidity and moist soil that the coarser the particles, the higher is the temperature during warm weather. A loose, open structure was always more favorable for high temperatures than one more finely pulverized. Walling's temperature differences, however, were very small, and it is probable that the experimental error, particularly due to lack of moisture control, was greater than the observed differences. Under normal conditions the practical effects arising from the influence of texture and structure on rate of absorption are probably entirely eliminated by other factors. The importance of texture and structure, as will be shown later, is in the direction of the control of soil heat through their influence on soil moisture. Moisture in turn is a potent factor in the ultimate soil temperature, as it influences specific heat, radiation, and expansion to such an extent.

214. Radiation of heat by soil.—The principal loss

¹ Walling, R. Untersuchungen über den Einfluss der Struktur des Bodens auf seine Beschaffenheit und Temperaturverhältnisse. *Monat. u. d. Göt. d. Agr.-Physik*, Band 7, Seite 145-220, 1882.

of heat by the soil is through radiation, this radiation being controlled by certain factors of which moisture content, soil texture, artificial coverings, ditches, and clouds are the most important. Color as a factor in radiation has already been eliminated by the work of Thompson and Lang. The effects of texture and structure have also been investigated by these authors, as well as by other physicists. The general results seem to indicate that when a dry soil is dealt with these factors may be eliminated from consideration so far as their direct practical effect on radiation is concerned. Of course, indirectly through their influence on water balance, they are of extreme importance.

As texture in the structure of a soil has the general effect of lightening the radiation ratio. This, together with the effects of compaction and of increased specific heat, accounts for the fact that an undisturbed soil in spring is a cold soil. Thompson¹ found the following relationships between moist and dry soils:—

RELATION OF MOISTURE TO RADIATION

| Soil | Temperature of Moisture | Temperature of Dry Soil | Ratio of Moisture to Dry Soil |
|------------------|-------------------------|-------------------------|-------------------------------|
| Gravel | 6.7 | 3.0 | 2.24 |
| Sand | 5.2 | 2.0 | 2.60 |
| Clay | 17.2 | 1.0 | 17.2 |
| Loam | 25.8 | 1.0 | 25.8 |
| Peat | 35.0 | 1.0 | 35.0 |

Moreover, either natural or artificial, tend to check the loss of soil heat through their covering effect and their

¹ Thompson, D. J. An Investigation of Soil Temperatures. Washington Agr. Exp. Sta., Tech. Bul. 27, p. 46, 1914.

influence on radiation. As a result it is usually dry, its radiant power is lower than that of the moist soil beneath. Shading decreases radiation by blocking air movement. The vegetation growing on soil also lowers radiation through its covering effect, although the temperature of soils covered with vegetation is usually low in summer due to the obstruction of the soil's rays. Clouds, by shutting in the heat, tend to check radiation and in many cases prevent a frost that would otherwise occur. The protecting effect of snow is well illustrated from the following data, taken from Hoesungwallt:—

WINTER OF SNOW ON SOIL TEMPERATURES¹ (TEMPERATURE IN DEGREES CENTIGRADES)

| Direction from | Air | On Snow | Under Snow |
|-----------------------------|-------|---------|------------|
| Feb. 11, 5 a.m. | + 2.5 | - 1.5 | 0.0 |
| Feb. 12, 7 a.m. | - 2.0 | - 12.0 | - 1.5 |
| Feb. 13, 7 a.m. | - 2.5 | - 5.2 | - 2.0 |
| Feb. 15, 12.30 p.m. | + 1.5 | 1.0 | 0.0 |

One of the important features of soil heat radiation is its effect on air temperature. As the radiant energy from the sun passes through the atmosphere, very little of the heat is appropriated, due to the wave lengths. But, as this energy is radiated from the soil, the heat waves have become shortened and are readily taken up by the atmosphere, particularly if the latter is moist. However, as the air is always in motion its heat is not controlled by the soil radiance of any particular locality.

¹ Wladimir, B. *Lectures on Physics of the Physical Properties of Soils*, p. 359. Oxford, 1906.

is, first, the soil may be warmed by conduction of heat from air to soil. This probably occurs to some extent in spring, when the air is growing warmer, due to low specific heat and its movement. The changes in air temperatures are always more rapid and usually greater in range, due to the factors cited above.

(13) *Conductivity and correction of heat in soils.*

While radiation has to do with the transfer of heat by ether waves, conductivity is a term used in relation to molecular transmission of energy through the body under investigation. It may be defined as the amount of heat in calories that will pass across a cube of unit edge (1 centimeter), in unit time (1 second) under a temperature gradient of 1 degree Centigrade. Correction refers to the transmission of heat by actual apparent and visible movements of matter. It is to these last modes of transfer that we owe the possibility of the soil's warming below a surface that receives most of its heat as radiant energy. It must be remembered that in studying the soil we are dealing with a material made up of mineral and organic components and always containing, under normal conditions, a certain quantity of water. Air likewise is always present, which, while a poor conductor of heat, may carry energy by convection. Besides these moving substances, then in loose contact and usually containing air capable of considerable movement, there is bound to occur a certain amount of transfer resistance which is the heat resistance found at the boundary of two substances in contact. The study of heat movement downwards through a soil is difficult to analyze, since it is almost impossible to control the factors concerned while varying any one. It is normal yet this heat movement occurs through both the agency of conduction and that of convection, depend-

ing on the texture and structure of the soil and the amount of moisture present.

20. **Measurement of conductivity.**—Ordinarily the conductivity of a soil is measured by applying a constant source of heat as quickly as possible and measuring the change in temperature by means of thermometers set in the soil at regular intervals. (See Fig. 45.) The soil in question should be homogeneous in composition and of uniform composition, and should contain a definite moisture content. It should of course be at a temperature equilibrium before the heat is applied. Ordinarily radiation and convection currents are diminished somewhat by insulating the soil in an insulated compartment. The study of heat movement downwards instead of laterally is to be recommended, in order that unnecessary air circulation may be avoided to some extent.

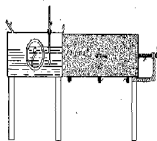


FIG. 45.—Longitudinal section of apparatus for the study of heat conductivity of soil. (H) water of constant temperature; (G) thermometer; (P) upper plates; (Q) lower plates for passing soil; (R) smaller plates for passing soil.

21. **Effect of texture on conductivity of heat.**—The conductivity of a soil is affected by a number of factors

which may or may not lend themselves to modification in the field. From the fact that type is of primary importance in choosing a soil, texture in its relation to conductivity might be considered first. From the work of Wigner¹ and Potts² it is clearly established that the coarser the texture of a soil, the better the rate of conduction of heat will be, other factors remaining constant. Data quoted from the findings of Koppmann³ substantiate these results:—

QUANTITATIVE OR VOLUMETRIC MEASUREMENT OF THE THERMAL CONDUCTIVITY OF DIFFERENT TYPES OF SOILS WITH THE SAME MOISTURE CONTENT

| Soil | Relative Thermal Conductivity |
|----------------|-------------------------------|
| Sand | 1.10 |
| Loam | 1.00 |
| Clay | 1.27 |
| Peat | 4.61 |

Such results as these are only comparative and qualitative. The difficulties of quantitative determinations are so great by error that only one investigator has as yet made any consistent attempt along this line. Pott⁴, who has conducted such an investigation, finds that such work may be vitiated by thermometer spacing, rate of observation, error in reading, moisture content, and

¹Wigner, F. Untersuchungen über die relative Wärmeleitungsvermögen verschiedener Bodentypen. *Bericht u. d. Ges. d. Agr. d. Phys.*, Band VII, Seite 1-34, 1905.

²Potts, B. Untersuchungen über die Methode der Verfolgung der Wärme in Boden durch Leitung. *Landw. Vers. Stat.*, Band XX, Seite 27-356, 1927.

³Koppmann, G. J. An investigation of soil temperatures. *Minnesota Agr. Expt. Sta. Tech. Bul.* 11, p. 20, 1912.

⁴Pott, B. D. *Landw. Vers. Stat.*, G. R. D. A., Vol. 20, Bd. 21, 1928.

the necessity of taking time-temperature curves in the unsteady state. His results, expressed as metric k (the heat conductivity coefficient in C. G. S. units), show the same general comparisons as already presented:—

Heat Conductivities as Determined by Russ

| Soil | k in C.G.S. units (See Definition of Conductivity) |
|---------------------------------|--|
| Course quartz | .00247 |
| Loessalluvium loam | .00282 |
| Podzolitic sandy loam | .00370 |
| Humic loam | .00399 |
| Chalky clay | .00427 |
| Mud | .00559 |

325. Effects of humus and structure on conductivity. — A disturbing factor always present when soils are used in the determination of the effect of texture on conductivity, is humus. It is evident, in dry soil at least, that an increase in the organic content of a soil means a lowering in conductivity. Humus, therefore, must be listed as a second factor tending to vary the movement of heat through soils. A third factor is the structural condition of the soil under examination. Wagner¹ has shown in this regard that the more compact a soil, the faster is the conduction of heat. This is probably due to the more intimate contact of the soil grains, and a consequent cutting-down of the insulation factors and diminution of the broader resistance.

326. Influence of moisture on heat conductivity in soil. — The greatest single factor to be considered in conduction

¹ Wagner, M. Untersuchungen über die Leitung Wärme im Boden. *Verhandlungen Versuchsstationen. Physik. u. d. Geh. d. Agri.-Physik, Band VI, Seite 1-51. 1885.*

viscosity itself, however, is the moisture content of the soil. The following curve for quartz powder, taken from Fig. 12, illustrates its effect and shows how its influence may heavily outweigh the factors already mentioned.

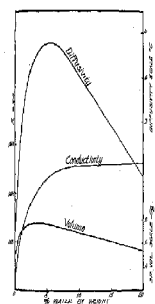


FIG. 12.—Effect of moisture upon the apparent specific volume, heat conductivity, and diffusivity of quartz powder.

¹ Holmes, H. R. *Heat Transfer in Solids*. U. S. G. A., Nat. Bur. 242, 53 p. 20, 1908.

At first glance it appears peculiar that the heat movement through a soil, the thermal conductivities of which possess a conductivity coefficient of about 0.008, should be raised by the addition of a liquid possessing a value of k of about 0.618, a conductivity about one-seventh of the soil solids. The explanation of this is given by Durnin in a lowering of the transfer resistance. He has calculated that heat will pass from soil to water approximately one hundred and fifty times more easily than from soil to air. This being true, it is evident that as the water is increased in any soil and the air decreased, the conductivity coefficient increases. It must be kept in mind, however, that as the moisture increases, the total amount of heat necessary to raise this soil to a given temperature must also be increased. The anomaly for the maintenance of a medium moisture content in any soil becomes apparent, although the conductivity may not thereby be at its maximum. The curves in question show that not only is there a change of volume weight, but also there is a decrease in density with high water percentages. Another reason for avoiding excessive moisture contents is a *dried* soil.

As has already been noted, the warming up of a soil becomes less and less rapid as the soil is penetrated. This is not due to lessened conductivity, but rather to a lessened heat supply. Bouyoucos¹ has shown that under natural conditions the tendency of heat is to spread downward more rapidly than laterally, due to a higher moisture in the lower depths of the average field soil. The time-temperature curves and the temperature gradients

¹ Bouyoucos, G. J., in *Intelligence of Soil Temperature*, Michigan Agr. Exp. Sta., Tech. Bul. 17, p. 25, 1915.

and the quartz powder as shown by Fisher¹ (see Figs. 50 and 51) illustrate the effect of distance on temperature rise, the conductivity coefficient remaining constant.

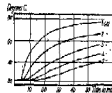


FIG. 10.—Temperature rise curves for quartz powder at various distances from the source of heat.

From this brief discussion of conductivity it may be established that such a measurement is of importance to plants in carrying heat downward into the soil. While it is affected directly by texture, structure, and moisture to a certain extent, moisture is the dominating factor. Under normal conditions it is necessary to maintain a sufficient moisture content, although the conductivity of heat is not three of its maximum. However, it must always be considered that correction is active under such conditions and may do much in facilitating heat distribution. Good tilth and increased organic content of any soil, by raising the optimum



FIG. 11.—Temperature profile for soil for various moisture contents.

¹Fisher, E. E. Heat Transfer in Soils, U. S. D. A., Bur. Tech., Bull. 20, pp. 25-26, 1906.

moisture content for plant growth, will place the soil in the best possible condition, consistent with plant need, openess, for good heat movement.

84. Effect of evaporation of water on soil temperature.

—There is perhaps no factor, besides the loss of heat by direct radiation, which exerts such an effect on soil temperature as does evaporation. The fact that water does not allow the long rays received by direct radiation to pass readily through it accounts for its rapid superheating. This evaporation, raised by an increased surface area itself, requires a certain expenditure of heat, resulting in a cooling effect on the water and consequently on any material in close contact with it. "To evaporate a pound of water requires the withdrawal of about 880 heat units? This is sufficient to lower the temperature of a cubic foot of saturated clay soil about 10° Fahrenheit. The difference in temperature calculated by wet and dry-bulb thermometers measures the cooling effect of evaporation.

Any condition that increases the rate of evaporation lowers the temperature of the surface concerned. The amount of water present is undoubtedly the controlling factor in this regard. King,¹ based, in his study of a dried and an undried soil in April, that the former maintained a temperature ranging from 22.5° to 15.5° Fahrenheit, higher than the latter. Fuchs² records the same general

¹An English land unit is the amount of energy necessary to raise one pound of pure water from 32° to 32° F. This equal to about 778 foot-pounds.

²King, P. H. *Principles of Agriculture*, p. 226. Published by the author, Madison, Wisconsin, 1910.

³Fuchs, J. On the Influence of Water on the Temperature of Soils. *Ann. Roy. Soc. Belg.*, Vol. 4, pp. 119-146, 1845.

results in England. Why? Leda's wet soil is to be the cooler in the daytime, the difference being roughly proportional to the amount of water present. The effect of the amount of water on the rate of expansion is of course influenced to a certain extent by texture, structure, and hence, also, these factors enter such a marked influence on water capacity and capillary movement.

The practical importance of a study of the effect of expansion on soil temperature lies in the fact that expansion can be controlled to a certain extent under field conditions. This is not so true, unfortunately, of radiation and convection. Through understanding of the dominant operation in the prevention of cooling by expansion. By the removal of excess water the specific heat is lowered, radiation is slightly retarded, and convection is facilitated. This means a faster warming of the soil, leading toward an optimum temperature relation as far as the plant is concerned. Optimum moisture maintains optimum heat coefficient, as well as other favorable relations whether chemical, physical, or biological. Drainage, fire, leaching, and other means to limit water as well as in other phases of soil improvement.

223. Effect of organic decay on soil temperature.— Besides the effect of organic matter on water and its consequent influence on the absorption of heat, it very frequently in another direction, namely, in producing heat of fermentation. Here for this liberation of heat under field

¹Whyte, E. Untersuchungen über den Einfluss des Wassers auf die Boden. *Monat. u. J. Ges. f. Agr.-Physik*, Band IV, Seite 257-261. 1901. Also, Untersuchungen über den Einfluss der Gärungs- und Fäulniswärme auf die Boden- und deren Temperatur- und Feuchtigkeitverhältnisse. *Monat. u. J. Ges. f. Agr.-Physik*, Band VII, Seite 225-231. 1906.

condition is effective in bringing about any important modification of soil temperature it is often difficult to decide. In greenhouses and hotbeds perceptible increases are obtained by the use of large quantities of fresh manure, as high as increase as 75 degrees Centigrade has been observed under such conditions. In the field, however, where the absorption and radiation of heat are very large, where the organic matter makes up only a fraction of the soil's components, and where the applications of barnyard manure are relatively small compared to the bulk of the soil, it is doubtful whether any important increase of soil heat actually occurs. Goessens,¹ working in dunes with varying quantities of manure, obtained during the first twenty days an excess over the check of only 3.4 degrees Fahrenheit from an application of eighty tons to acre. With twenty tons the increase was 1.7 degrees. Wagner² obtained similar results, finding an average excess of 1 degree Fahrenheit from the use of twenty tons of barnyard manure. Goessens³ has obtained the latest data on this subject. Under controlled laboratory conditions he found that when excessive amounts of manure were applied no appreciable effects were observed. With an application of ten tons the highest rise was one-half degree Centigrade; after one tonched and three days the treated soil was only one-fourth degree higher than the untreated. Such results show that the best of fertilization has little important practical influence

¹ Goessens, O. C. Influence of Manure on Soil Temperature. *Ag. Sci.*, Vol. 1, pp. 24-35, 1907.

² Wagner, F. Über den Einfluss der Düngung auf die Temperatur des Bodens und die Bodenfeuchtigkeit. *Jahrb.* 5-6, *Bd. d. Agt.-Physik*, Band 7, Seite 275-296, 1902.

³ Goessens, O. J. An Investigation of Soil Temperature. *Michigan Agr. Exp. Sta.*, Tech. Bul. 17, pp. 186-205, 1913.

on soil temperature, so far as the total bulk is concerned. There are without doubt certain localized influences, both chemical and biological, but how important they may be it is rather difficult to say. From what is known at the present time it seems that organic matter tends to produce temperature effects through the dissolving of the water and the increase in moisture capacity of the soil.

516. *Relation of slope to soil temperature.*—The relation of exposure to soil heat is the last phase to be considered, with the exception of meteorological factors, which are referred in their relationship rather than intrinsically as have been most of the phases already discussed. The slope of a surface varies the amount of heat absorbed from the sun, without affecting, of course, the absorptive power of the surface involved. The greater the inclination of a soil from a right-angle interception of the heat rays, the less rapid will be the rate of temperature in a given unit of time; the steeper the inclination, the greater is the amount of surface exposed to the heat rays. It is evident that a less amount of heat will reach each unit of soil surface, and a consequent slower rise in temperature of the soil so situated will result. Under normal conditions, therefore, any inclination that will cause a surface to approach a right-angle interception of the sun's rays will not only increase the rate of temperature rise but at the same time will increase the average seasonal temperature. In the North Temperate Zone this of course is a southerly inclination. The following diagram, illustrating the variations on the 45° parallel at noon on June 21, makes clear this relationship.

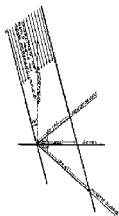


FIG. 54.—Diagram showing the proportional amount of heat received by the vertical area at different latitudes as here 30° , at the 60° parallel north.

It is seen that in this case a southerly slope of 30° receives as much area the greatest amount of heat, the level soil and the soil having southerly inclination of 30° differing in the ratio named. The following table shows the proportional amount of heat received by each one of these soils per unit area at midday with such an inclination of the sun's rays:—

PROPORTIONAL AMOUNT OF HEAT RECEIVED PER UNIT AREA OF DIFFERENT SURFACES ON JUNE 24, AT THE EQUINOXIAL WINTER EQUINOX.

| |
|------------------------------------|
| 30° Southerly slope = 106 |
| Level = 100 |
| 30° Northerly slope = 81 |

These figures show not only that the slope itself is important, but also that the direction of the inclination must play a part in the inference of heat with its probable temperature relationship thereto in mind. The investigations of Wölffy,¹ which have since been corroborated by King,² and others, may be cited at this point as typical:

ICEBERG TEMPERATURE AT 6 LOCATIONS UP A HERRING RIVER
FROM NINE TO TWENTY, 1877, MICHIGAN. GROSSMAN

| | Temperature in Degree Centigrade |
|---------------------|--|
| South | 11.55 |
| Southeast | 14.42 |
| Southeast | 14.42 |
| East | 13.89 |
| West | 13.85 |
| Northwest | 12.44 |
| Northwest | 13.55 |
| North | 13.12 |

¹ Wölffy, E. Untersuchungen über den Einfluss der Exposition auf die Erwärmung des Bodens. *Bericht. a. d. Ges. d. Agr.-Physik, Band 1, Seite 263-294, 1879; Untersuchungen über die Pflanzentheil- und Temperaturverhältnisse des Bodens bei verschiedenen Stellungen des Horizonts gegen den Horizont. *Annal. u. d. Ges. d. Agr.-Physik, Band 12, 479-121, 1891; Untersuchungen über die Pflanzentheil- und Temperaturverhältnisse des Bodens bei verschiedenen Stellungen des Horizonts gegen die Sonnenrichtung und gegen den Horizont. *Bericht. u. d. Ges. d. Agr.-Physik, Band 12, Seite 1-44, 1892; Untersuchungen über die Temperaturverhältnisse des Bodens bei verschiedenen Stellungen des Horizonts gegen die Sonnenrichtung und gegen den Horizont. *Annal. u. d. Ges. d. Agr.-Physik, Band 12, Seite 145-184, 1892.****

² King, H. E. *Physics of Agriculture*, p. 246. Published by the author, Madison, Wisconsin, 1910.

Wolfe found also that the soil temperature on the southward slopes varied according to the time of year. For example, the southerly inclination was highest in the early season, the southerly slope during mid-season, and the southerly slope during the fall. A southwesterly slope is usually favored by grasses. Ordinarily also pay strict attention to aspect, as it often is a factor in susceptibility to soil wind and other diseases.

King, in comparing a red clay with a southerly slope of 18° to that on a level on July 24, obtained the following results:

TEMPERATURE IN DEGREE FARENHEIT OF RED CLAY ON INCLINATIONS OF SLOPE

| | Four Feet | Eight Feet | Twelve Feet |
|-----------------------|-----------|------------|-------------|
| Southerly slope . . . | 70.1 | 68.3 | 66.4 |
| Level | 67.2 | 65.4 | 63.8 |
| | 3.1 | 2.7 | 2.6 |

It is apparent immediately that the influence of slope is not confined to the surface, but, owing to convection and convection, is felt to a considerable depth. Slope, therefore, together with moisture control, becomes a dominant factor in the best relations of a soil. This is particularly true with specialized crops, with which the early watering of the soil is important. A normally early soil may become early due to exposure, or a normally late soil may become earlier due to an inclination southward. Slope may thus be a decisive factor in the adaptation of crop to soil.

467. Heat supply and its effects.—The direct heat supply is without doubt the controlling factor in soil

temperature, influenced, of course, by the conditions already discussed. The effect of this last supply is reflected in the seasonal, monthly, and daily temperatures in the surface and at varying depths below. The following data illustrate the differences that may ordinarily be expected to take place from season to season on an average soil.

SEASONAL TEMPERATURES, RAINFALL, AND HUMIDITY, CHICAGO¹—AVERAGE OF THE YEARS, 1861-1900 (IN DEGREES FARENHEIT)

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|------|------|------|------|------|------|------|------|------|-------|------|------|------|
| Max. | 58.4 | 58.2 | 57.2 | 54.9 | 57.1 | 58.7 | 60.6 | 61.5 | 62.2 | 60.5 | 58.4 | 56.4 |
| Min. | 43.6 | 43.3 | 43.2 | 43.5 | 44.3 | 45.1 | 45.7 | 46.2 | 46.5 | 46.8 | 47.1 | 47.5 |
| Mean | 46.0 | 46.7 | 48.6 | 49.6 | 50.6 | 51.9 | 53.0 | 53.3 | 53.3 | 53.3 | 53.3 | 53.3 |

SEASONAL TEMPERATURES, RAINFALL, AND HUMIDITY, MOBILE²—AVERAGE OF THE YEARS, 1900-1922 (IN DEGREES FARENHEIT)

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|------|------|------|------|------|------|------|------|------|-------|------|------|------|
| Max. | 58.0 | 58.0 | 58.0 | 58.0 | 58.0 | 58.0 | 58.0 | 58.0 | 58.0 | 58.0 | 58.0 | 58.0 |
| Min. | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 |
| Mean | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |

¹Heide, R., and Farnsworth, H. Beschreibungen über Temperaturverhältnisse des Jahresverlaufs und verschiedener Tiefenlagen. Internat. Mitth. für Landwirtsch. Beob. II, Teil 2, Seite 120-140, 1922.

²Howes, G. D. Air Temperature at Mobile, Alabama. Monthly Rep. No. 1900 Ann. Rept., pp. 92-101, 1902.

These average readings, taken at different points, are supported by the data of other observers.¹ It is apparent that seasonal variation of soil temperature is considerable, even at the lower depths. The surface layers of soil seem to vary nearly in accord with the air temperature, and therefore exhibit a greater fluctuation than the subsoil. In general the surface soil is warmer in spring and cooler than the lower layers, but cooler in fall and winter. The following data taken at Lissolski, Kholminka, may be of interest:—

ANNUAL MONTHLY TEMPERATURE READINGS TAKEN AT LISSOLSKI, Kholminka. AVERAGE OF TWENTY YEARS.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|-----------|------------------|------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|
| | At 100 cm. | Surface temp. | 10 cm. | 20 cm. | 30 cm. | 40 cm. | 50 cm. | 60 cm. | 70 cm. | 80 cm. | 90 cm. | 100 cm. |
| January | 22.2 | 27.3 | 27.9 | 28.6 | 29.0 | 29.0 | 29.1 | 29.2 | 29.4 | 29.5 | 29.6 | 29.6 |
| February | 26.5 | 27.7 | 27.9 | 27.9 | 27.9 | 28.0 | 28.1 | 28.2 | 28.2 | 28.3 | 28.3 | 28.3 |
| March | 28.8 | 28.7 | 28.7 | 28.7 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 |
| April | 31.3 | 27.5 | 28.0 | 28.3 | 28.5 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 |
| May | 31.0 | 28.7 | 27.5 | 28.1 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 | 28.3 |
| June | 27.0 | 28.1 | 28.0 | 27.7 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 |
| July | 26.9 | 28.1 | 28.0 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 | 27.6 |
| August | 24.5 | 25.8 | 25.3 | 25.1 | 25.1 | 25.1 | 25.1 | 25.1 | 25.1 | 25.1 | 25.1 | 25.1 |
| September | 22.5 | 22.8 | 22.4 | 22.0 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 | 21.7 |
| October | 22.5 | 22.7 | 22.4 | 21.9 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 |
| November | 20.7 | 20.7 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 | 20.3 |
| December | 21.2 | 21.2 | 21.4 | 21.4 | 21.4 | 21.4 | 21.4 | 21.4 | 21.4 | 21.4 | 21.4 | 21.4 |
| Average | 28.19 | 28.52 | 27.5 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 | 27.8 |
| Range | 55.6 | 27.6 | 36.3 | 33.9 | 31.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |

¹ Koenig, E. Untersuchungen über den Verlauf der Temperatur im Boden gegen Wärm. Arch. u. d. Geol. d. Agr.-Physik, Band 34, Seite 285-293, 1879.

² Hering, O. D. Soil Temperature in Ussels, Kholminka. Nishnolig. Agr. Exp. Sta., Ann. Agr. Exp. Sta., 1905, 3063.

The upper soil layers vary in accordance with the air temperature; the maximum and the minimum occurring in the same month. A lagging (see Fig. 43) is apparent in the annual, due to the slow response of this area to the heat penetrating from above. These figures also show the surface soil to be warmer in spring and summer, and cooler in winter and fall, than the lower depths. The surface soil not only never falls so low in temperature as the air, but reaches a higher point in summer. This is shown in the range of the air and soil temperatures. The range for the air is 34.8°, while that for the soil is 47.5°, 24.5°, 53.8°, 31.0°, 41.5°, 38.1°, and 24.0°, respectively, for the depths ranging from 1 inch to 36 inches. While this range of soil temperature is greater in the aggregate than that of the air, the changes are much slower and often extend over a number of days, while the *air* may vary many degrees in an hour.

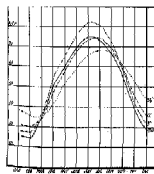


FIG. 43.—Comparing the range monthly temperature variation of surface and depths. Average of twelve years, Lincoln, Nebraska.

The daily and hourly temperature of the air and the soil may be fairly constant or rather variable, according to conditions. On days of sunshine, however, considerable changes may be expected. The air temperature rises from morning until about two o'clock, when the maximum is reached. It then falls rapidly. The soil, however, does not reach its maximum temperature until later in the afternoon, due to the lagging so apparent in soil temperature changes. This lagging is greater in the lower layers than at the surface. The following data, taken on a bright day on May 26 in Germany, illustrate the ordinary differences that may be expected in soil and air temperatures:—

TEMPERATURE MEASUREMENTS IN GERMANY ON MAY 26, 1914, ON A LOUSE-POLE AT 6-10 CM. DEPTH (IN DEGREES FARENHEIT)

| Time | Air | Soil 6 in. |
|----------|------|------------|
| Midnight | 65.4 | 63.5 |
| 2 A.M. | 64.2 | 63.1 |
| 4 " | 65.7 | 63.6 |
| 6 " | 67.6 | 67.0 |
| 8 " | 71.4 | 68.4 |
| 10 " | 82.0 | 68.7 |
| Noon | 85.3 | 69.8 |
| 2 P.M. | 89.5 | 74.8 |
| 4 " | 88.1 | 77.1 |
| 6 " | 79.1 | 77.7 |
| 8 " | 68.7 | 73.9 |
| 10 " | 65.3 | 69.8 |

*Wolff, R. Untersuchungen über den Einfluss der Witterungsverhältnisse auf die physikalischen Eigenschaften des Bodens. *Monat. u. d. Ges. f. Agr.-Physik*, Band 4, Seite 137-150. 1886.

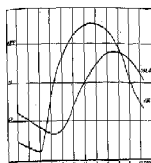


FIG. 51.—Change showing the hourly temperature of bare soil at a depth of four inches and of the air above the soil. May 16, 1916.

The temperature of the soil at the surface may often exceed that of the air, and the amount of daily fluctuation may be greater, but for the lower depths the temperature curve flattens out. The subsoil shows but little daily, and even monthly, variation, and is affected only by seasonal changes.

238. Control of soil temperature.—The means of practical control and modification of soil temperature are those commonly in vogue in good soil management. The most important factor is, of course, soil moisture. Good drainage, proper tillage developed by deep plowing, stony of time, and sufficient organic matter, favor optimum moisture conditions. Such moisture regulation means a lowered specific heat and good conductivity. The use of a soil mulch or an artificial covering at, early will check convection but will scarcely retard loss of heat by radiation. Any farmer who so outside his soil

condition that optimum conditions so far as the plant is concerned may be obtained, should have no fear of a poor utilization of land.

The increase of soil humus, of course, may act directly in heat control by darkening the color and increasing absorption. A soil moist, being dry, not only checks evaporation but lowers radiation while increasing absorption. Any methods of heating the land which tend to better the physical condition of the soil and increase its fifth heat also toward a proper heat control at the same time. The whole question may be summarized by saying that if a farmer adopts a proper system of moisture control and at the same time employs methods that tend always toward a better physical condition of the soil, the problem of control of soil heat will be automatically solved. He will then have brought about the best conditions for heat absorption and will have facilitated evaporation and convection, while at the same time retaining heat by convection and insulation.

CHAPTER XV

AVAILABILITY OF PLANT NUTRIENTS AS DETERMINED BY CHEMICAL ANALYSIS

For purposes of analysis, only measurably soluble properties of the soil is at any one time soluble in water so in the aqueous solutions with which it is in contact. It is this great degree of insolubility that gives the soil its permanency, for in humid regions, without this property, it would be rapidly carried away in the drainage waters. The portions of the soil that is soluble in the various natural solvents with which it comes in contact facilitates all essential materials for plants. The great mass of soil, which is relatively insoluble, is constantly subjected to natural processes which very slowly bring its constituents into solution. The agents that are concerned in the decomposition of rock also act on the soil to bring about its further decomposition, and thereby render it more soluble; while added to these are the operations of tillage, which contribute to the movement.

Only the surfaces of the soil particles come into contact with the decomposing agents, and hence it is the surface matter of the particles that gradually goes into solution. The factors that determine how rapidly solution shall proceed are: (1) the amount of surface exposed, which, as has been seen, varies with the size of the particles; (2) the composition of the particles; (3) the strength of the decomposing and solvent agencies. Were it not for this

process, there would soon be no mineral food available to plants, as drainage water and the growth of crops take up relatively large quantities of these substances each year; but in spite of this loss the soil is able to provide at least some plant-food material for each crop, when called upon by the plant.

229. *Solubility of the soil in various solvents.*—For purposes of analyses that are intended to show the amounts of mineral plant-food materials in a soil, any one of several different solvents may be used. These solvents differ in strength, and consequently the percentages of the various constituents obtained from samples of the same soil are different for each solvent. A chemical analysis of a soil is a determination of the quantities of the constituents that have been dissolved in the solvent used. Therefore it will readily be seen that the interpretation of a chemical analysis must depend largely on the nature of the solvent, and, unless the solvent is equivalent in its action to some process or process in nature, the results must be entirely arbitrary.

The methods that have been used for obtaining solutions of the soil for analysis may be grouped as follows:—

1. Complete solution of the soil.
2. Partial solution with strong acids.
3. Partial solution with weak acids.
4. Extraction with water.

130. *Complete solution of the soil.* By the use of hydrofluoric acid and sulfuric acid and by fusion with alkalis the entire soil mass may be decomposed and all its nutrient constituents determined.¹ Such an analysis shows

¹ Wiley, Harvey W., *Principles and Practice of Analytical Chemical Analysis*, Vol. 1, pp. 332-338, 1906.

the total quantity of the plant-food materials except nitrogen, which is now determined in one of the soil solutions but by a separate process.¹ A deficiency of any particular substance may be discerned in this way, but nothing can be known as to the ability of the plant to obtain nutriment from the soil. A rock may show as much mineral plant-food material as a rich soil. This method of analysis is used only to ascertain the ultimate limitations of a soil or its possible efficiency in any normal conditions. Results of such analyses are to be found in paragraphs 45, 46, 47, 48, 49 of this text.

211. Partial solution with strong acids. While sulfuric, nitric, and hydrochloric acids have all been used as solvents,² the one most commonly employed is hydrochloric acid of 1.18 specific gravity.³ It has been used to such an extent that it may be considered the standard solvent, and a statement of a chemical analysis of a soil in this country may be considered as based on this solvent unless otherwise noted.

¹ Official and Commercial Methods of Analysis, U. S. D. A., Proc. (Comm., Div. 137 (revised), p. 19, 1909.

² Also just using concentrated material with one of the acids will, New England, Quincy, Mass. Massachusetts Agr. Exp. Sta., Bul. 6, p. 64, 1896.

| | Percent in acid | Percent in water | Percent in soil |
|---------------------------------------|--------------------|---------------------|--------------------|
| Total fertilizer percentage | 84.20 | 85.45 | 86.45 |
| Phosphorus percentage | 0.45 | 0.50 | 0.55 |
| Nitrogen percentage | 0.55 | 0.50 | 0.55 |
| Potassium percentage | 0.60 | 0.52 | 0.52 |
| Fluorine acid percentage | 0.58 | 0.51 | 0.51 |
| Sulfuric acid percentage | 0.58 | 0.50 | 0.50 |

³ Official and Commercial Methods of Analysis, U. S. D. A., Proc. (Comm., Div. 137 (revised), pp. 14-15, 1909.

An analysis by this method is supposed to show the proportion of plant-food materials in a soil that are in a condition to be ultimately used by plants at the time when the analysis is made, and the plant-food materials that are not assimilated by treatment with hydrochloric acid are assumed to be in a condition in which plants cannot use them. The difficulty with this assumption is that, while treatment with hydrochloric acid of a given strength marks a definite point in the solubility of the compounds in the soil, it does not bear a uniform relation to the actual processes by which these compounds become available to the plant.

In the case of most soils a large proportion is not so composed by treatment with strong hydrochloric acid, and the portion that is dissolved may contain a larger or a smaller quantity of the agriculturally important elements, depending on the character of the soil. Thus if calcium is present as a phosphate, a large proportion will be dissolved by the acid than if it is in the form of silicate. The form in which potassium occurs also influences greatly the amount shown by analysis.

Stephens¹ has analyzed a number of soils by means of digestion with strong hydrochloric acid, and has then decomposed the acid-insoluble residue by fusion and determined its composition. Vezich² has analyzed soils by the hydrochloric acid method and by means of complete solution. A few examples are given below to show how soils may vary in the solubility of their constituents in strong hydrochloric acid:—

¹ Stephens, Henry. *Bull. Minnesota Agr. Exp. Sta.*, Bul. 41, p. 55, 1907.

² Vezich, F. P. *The Chemical Composition of Manures*. *Bull. Maryland Agr. Exp. Sta.*, Bul. 70, p. 103, 1901.

PERCENTAGE OF CHLOROPHYLL IN ROOTS OF 700,
1,115 *et. al.*

| | THIS YEAR'S GROWTH | | | THIS YEAR'S GROWTH | | |
|------|--------------------|---------------------|---------------------|--------------------|---------------------|---------------------|
| | Per Area | Per Unit Area | Per Unit Area | Per Area | Per Unit Area | Per Unit Area |
| 1900 | 36 | 31 | 83 | 15 | 47 | 71 |
| 1901 | 25 | 41 | 41 | 10 | 32 | 37 |
| 1902 | 38 | 70 | 23 | 24 | 29 | 28 |
| 1903 | 40 | 45 | 18 | 66 | 18 | 0 |
| 1904 | 74 | 10 | 21 | — | — | — |

12. Significance of a strong hydrochloric acid analysis.

—This method of analysis was originally thought to give some indication of both the permanent fertility and the immediate chemical needs of a soil; but for such question the accuracy of the deductions is limited by a number of conditions that make it impossible invariably to predict from an analysis how productive a soil may be or what particular measure may be profitably applied. It is very apparent that the chemical composition of a soil is only one of the many factors affecting its productivity. Unfortunately, not all the factors are understood and consequently their influence can never be determined either qualitatively or quantitatively. If it were becomes possible to determine quantitatively all the factors entering into soil productivity in the field condition, the problem will be solved.

13. Relation of texture to stability. The ratio of sand to clay in a soil, and the distribution of the fertilizing materials in these constituents, will affect the mini-

most quantity of any constituent required to produce a good crop. Elwood has shown that the addition of four or five volumes of quartz sand to one volume of a heavy, but highly productive, black clay will greatly increase the productivity, while diluting the potash content of the mixture to 0.15 per cent and the phosphoric acid to 600 per cent. It is evident that in this soil the plant-food materials were in a condition to be easily taken up by the plant when the physical condition of the soil was suitable.

If down small quantities of food elements had been distributed in the small particles as well as in the original clay, the results would doubtless have been different. Suppose, for example, that fifty per cent of the potash and phosphoric acid had been in the small particles and the remainder in the clay; in that case the former, in a soil separating with the bare surface to dissolving rapidly, would be proportionately less available, and as the minimum quantity is approached, as shown by the more dilute soils yielding less than the other, the effect would doubtless have been to decrease the production. In some soils, particularly those of arid regions, the larger particles may carry much of the mineral nutrients, in which case it is quite evident that a higher percentage of fertility is required than in soils carrying the plant-food material largely in the small particles.

26. Nature of the subsoil.—The nature and composition of the subsoil is naturally a factor in determining soil-productiveness, and must be considered as well as the top soil. An impervious subsoil, or a very fine sandy one, will confine the productive zone largely to the topsoil and hence require a greater proportional amount of fertility in that part of the soil.

25. Calcium carbonate.—A determination of the percent of calcium present as a carbonate is important for its aid in the interpretation of an analysis of the soil. Lime not so combined is generally in the form of a silicate, or possibly a phosphate. If there is a large quantity of calcium carbonate in a soil, the potash, phosphoric acid, and nitrogens are likely to be more readily soluble, and smaller quantities are sufficient for crop growth, than if the calcium is not found in this form. The effect of the carbonate of lime on the nitrogen¹ compounds is to furnish a base for the acids produced in the formation of nitric acid, and the process promotes this process. It probably explains why nitric acid is certain compounds where otherwise it would be mixed with more difficulty. It causes the presence of some phosphates of lime, in which form phosphorus is more soluble than when combined with iron. The form of the measure to be used on the soil will also depend in large measure on the presence or the absence of calcium carbonate. For example, where calcium carbonate is deficient, steamed bone or Thomas slag are likely to be more profitable than superphosphate, and nitrate of soda than sulfate of ammonium. Finally the absence of calcium carbonate indicates the need of liming, and if the samples show a considerable quantity of potash and phosphoric acid, but practice shows these materials to be somewhat deficient, it is probable that liming will be very beneficial, and that steaming or using these substances will not be so essential as the chemical analysis would indicate. It must be stated, however, that there are cases in which these indications do not hold, owing to the intervention of other factors.

¹ Nitric acid is formed in the hydrolytic acid nitrate.

200. Deficiency of important and essential needs.

Many standards have been set for the minimum quantity of each of the important soil constituents that must be present in order to insure a productive soil. Experience has shown, however, that no definite standards hold for all soils. By comparing analyses of soils of known productivity with that of a soil under investigation it is an easy matter to ascertain whether the soil contains a large quantity of each agriculturally important ingredient, but when the quantity of any constituent is low, it becomes a difficult matter to tell how this will affect the agricultural value of the soil. Some soils will be productive with 0.5 per cent of phosphoric anhydride, while others are unproductive when all the plant nutrients are present in ample quantity.

The fact that the degree of productivity of a soil cannot always be gauged by its analysis gives rise to a similar uncertainty with regard to its essential needs. A soil may contain potassium in very large quantities, sufficient to produce crops for hundreds of years, as indicated by a strong hydrotimetric acid analysis, and yet a potassium salt may be used with profit. On the other hand, it is evident that as the content of any constituent becomes less, the probable need for its application becomes greater, and a knowledge of the composition of the soil thus suggests a practice without assuring its success. An analysis of the hydrotimetric acid extract, therefore, cannot be taken as an infallible guide to the fertilizer needs of a soil, and of itself should not be relied upon; but in connection with other knowledge, particularly that derived from fertilizer tests, it may be useful.

201. Fertilizer solutions with weak acids.—The difficulty in judging the properties of a soil from the results of

a strong hydrochloric acid analysis has led to the use of weak acids for obtaining the solution. These weak acids dissolve more base of the soil constituents than do the strong acids, and the portion so dissolved is supposed to represent more nearly the amount that the plant can make use of. Both dilute organic acids and dilute mineral acids have been used. Among the former are citric, tartaric, malic, and lactic acids. The assumption on which the use of the organic acids is based is that they correspond to the solvent agents in the soil combined with the solvent action that the plant is supposed to possess, and that therefore from the soil the quantities of nutrients that the plant could take up if it came in contact with all the soil particles to a depth represented by the sample analyzed.

23. Advantage in the use of dilute acids.—The action of each of these dilute acids on the same soil does not give equal quantities of the various constituents in solution. The dilute acids naturally dissolve a much smaller amount of material from the soil than does strong hydrochloric acid. The dilute acids permit the detection of smaller quantities of easily soluble phosphorus and potash than does the latter, larger quantities of soil being used. For example, a chemical analysis of the strong hydrochloric acid solution is very likely not to show any increase in the phosphorus or potassium in a soil that may have been abundantly manured with these fertilizers and its productivity greatly increased thereby. This is because the amount of plant-food material added is so small in comparison with the weight of the acre of soil that before long more will be in general that the increase in percentage may well come within the limits of analytical error. An acre of soil nine inches deep weighs about

2,500,000 pounds. If to this there is added a dressing of 5000 pounds of phosphoric acid fertilizer containing 40 per cent of phosphoric acid, it would increase the percentage of that constituent in the soil only 0.043 per cent—a difference that could not be detected by the analysis of the hydrochloric acid solution.

298. *The one-per-cent citric acid method.*—This method was proposed by Dyer¹ and was shown by him to give results with Lithuanian soils that pertained of an accurate estimation of their relative productivity. Dyer adopted the one-per-cent strength as the result of an investigation in which he determined the acidity of the juices in the roots of over one hundred species or varieties of plants representing nearly different natural orders. The average acidity of the juices of the twenty orders, calculated as undiluted citric acid, was 0.01 per cent, which led Dyer to adopt a strength of 1 per cent. It must be said, however, that the different varieties varied greatly in this respect, some having ten times as much acidity as others. The implication is that plants produce a solvent action on a soil in proportion to the acidity of their juices, but an examination of Dyer's figures does not show that the size of the crop actually produced by the plants tested would in many cases correspond to the acidity of these juices. Thus, of the *Candollea* the borealis has several times the acidity of the *Swedish turnip* or of the *Sail cabbage*, although the crop produced by the former is much less than that of the latter.

299. *Usefulness of the citric acid method.*—As shown by Dyer, the use of a one-per-cent solution of citric

¹ Dyer, Horner, "On the Analytical Determination of Phosphorus Available 'Mineral' Plant Food in Soils," *Proc. Chem. Soc.*, Vol. LXV, pp. 115-117, 1894.

acid is well adapted to show the amount of easily soluble phosphate acid and potash in certain soils, but for other soils it has failed to give satisfaction in the bulk of a number of analytical. It is doubtless best suited to soils rich in calcium and low in iron and aluminum.

The reason urged by Fyfe for the superiority of the citric acid method over the hydrochloric acid extraction is that soils, shown by experience to need phosphoric manures, yielded a relatively much greater quantity of phosphate in citric acid than to hydrochloric acid when compared with soils not needing this element.

The application of both the hydrochloric and citric acid methods to a soil, when used to supplement each other, may add greatly to a knowledge of the potential and present productiveness of the soil.

According to Dyer,¹ for cereals and for most other crops there should be present in a soil at least 31 per cent of phosphoric acid, soluble in one-per cent citric acid, & soil containing less than this quantity is deficient in phosphoric acid, unless this acid exists largely in the form of ferric or aluminum phosphates, which is not readily soluble in citric acid but is fairly available to the plant. Soil does contain organic compounds of phosphorus that are readily available to the plant; hence such soil, to indicate sufficiency, should show by analysis more than 501 per cent of phosphoric acid. The quantity of potash soluble in the same solvent should also be not less than 501 per cent in arable land.

¹Dyer, Thomas. A Chemical Study of the Phosphates (and also Potash) Products of the Werns Mills of Broadbalk Field, Rothamsted. Edinburgh, Trans. Royal Soc. London, 1896, 1, Vol. 284, pp. 227-290. 1910.

24L. Other mineral acids.—Of the mineral acids in a diluted form used for extracting soils, those that have received the most attention are oxalic¹ normal nitric¹ or hydrochloric acid and one two-hundredth normal hydrochloric acid.² The methods employing these solvents are absolutely empirical. There is no rational relation between these solvents and the processes by which the phosphates are extracted from the soil.

The solvent that has received the most attention is oxalic, normal, citric acid. In case of oxalic acid this is preferable to the two-hundredth normal acid, which is rather tedious to work with. It has been used much as extensively in this country as the latter has in Great Britain. Its use has been confined largely to the determination of the readily available phosphorus and potassium in the soil, as has the citric acid method. It is obvious that some minerals are more readily soluble than others, and that even the method will distinguish between phosphorus and potassium in different forms. The calcium phosphates are known to be readily soluble in this solvent. According to Frazer³ it dissolves iron and aluminum phosphates in only a slight extent, thus distinguishing between these forms of phosphorus. Frazer finds also that no potassium is removed from orthoclase and microcline, that less than ten per cent is dissolved

¹ Official and Provisional Methods of Analysis. U. S. D. A., Bur. Chem., 2nd. 277 (revised), p. 28, 1905.

² Wang, G. W. Principles and Practice of Agricultural Analysis, pp. 294-303. Boston, Poughkeepsie, 1908.

³ Frazer, G. S. Action Phosphoric Acid and Its Relation to the Tests of the Soil for Phosphorus, 1911, p. 1103. Also, The Action Potash of the Soil and Its Relation to Pot. Experiments. Trans. Agr. Soc. Scot., 1911, 44, pp. 5-28. 1912.

from glauconite and biotite, and that from illite to clay per cent is derived from muscovite, sepiolite, leucite, apophyllite and phillipsite.

There are several factors, however, that make the use of cationic nutrient tests as a means of guide to the available phosphorus and potassium in the soil. When a soil is treated with the soil mass of it is restricted by its reaction that result and thus its strength is lowered. This may have no relation to the quantities of phosphorus or potassium dissolved. Some analysis errors for the calculation and some do not. Again, as with strong hydrochloric acid, the degree of solubility of the soil components in the acid may not correspond with the ability of the plant to obtain these substances. With this, as with the other methods discussed, the objective is that the result cannot be taken as an infallible guide to the productivity of a soil, or to its fertilizer needs; but each of the methods affords some information in regard to a soil, and is thus of value.

32. Extraction with an aqueous solution of carbon dioxide. - An aqueous solution of carbon dioxide is a universal solvent of the water of the soil, and without doubt a potent factor in the decomposition of the mineral matter, it has been proposed to use a solution of carbon dioxide as a solvent in soil analysis. The amounts of soil constituents taken up by this solvent are much less than are taken up by any of the others mentioned previously, but all mineral substances used by plants are soluble in it to some extent. The amount of phosphorus is so small as to make its detection by the gravimetric method difficult. Like other methods employing very weak solvents, this method is open to the objection that the extraction fails to remove a considerable portion of the dissolved matter that is

retained by absorption, and as this varies with soils of different texture a fair comparison of such soils is impossible.

243. Extraction with pure water.—When soil is digested with distilled water, all the mineral substances used by plants are dissolved from it, but in very small quantities. It has been proposed to use this extract for soil analysis on the ground that it involves no artificial solvent the presence or amount of which in the soil is doubtful, but dissolves those substances that are immediately in a condition to be used by plants. By determining the water content of the soil and using a known quantity of water for the extraction, the percentage of the various constituents in the soil water or in the dry soil may be calculated.

The substances dissolved from the soil by extraction with distilled water are probably only those contained in the soil-water solution, including a part of the solutes held by absorption. The aqueous extract does not contain the entire quantity of the extractive solids in solution in the soil water, and hence is not a measure of the fertility held in that form. An undetermined quantity of nutrients is retained in the water in the very small spaces and on the surface of the soil particles. It is, however, a fair comparative measure of the amount of available nutrients.

244. Influence of absorption.—The quantity of extracted material depends on the absorptive properties of the soil and on the amount of water used in the extraction, or on the number of extractions. Analyses of the aqueous extract of a clay soil and of a sandy soil on the Cornell University farm serve to illustrate the greater retentive power of the former for nutrients. Soluble nitrate was

applied to a clay soil and to a sandy loam soil at the rate of 100 pounds to the acre. Analyses of various extracts were ninety days later showed the following:—

| Time in Years | Fertilizers | Extracts (in lbs.) (Pounds per acre) |
|----------------------|------------------|--------------------------------------|
| Clay | Sulphate nitrate | 1.5 |
| Clay | No fertilizer | 1.5 |
| Sandy loam | Sulphate nitrate | 65.0 |
| Sandy loam | No fertilizer | 28.7 |

There was apparently a much greater retention of nitrate by the clay soil, as shown by a comparison of the fertilized and the unfertilized plots on both soils.

Schulze* extracted a rich soil by slowly leaching 1000 parts with pure water, so that one liter passed through in twenty-four hours. The extract for each twenty-four hours was analyzed every day for a period of six days. The total amounts dissolved during each period were as follows:—

| Fertilizer Description | Total Material Dissolved (Grams) | Nitrogen (Grams) | Phosphorus (Grams) |
|------------------------|----------------------------------|------------------|--------------------|
| First | 0.555 | 0.246 | 0.196 |
| Second | 0.520 | 0.087 | 0.065 |
| Third | 0.598 | 0.101 | 0.100 |
| Fourth | 0.555 | 0.083 | 0.129 |
| Fifth | 0.550 | 0.082 | 0.119 |
| Sixth | 0.550 | 0.087 | 0.125 |

*Schulze, P. Ueber das Fertilisierungs-Gebiet des Phosphors der Ackererde. Landw. Vers. Stat., Heft 6, Seite 159-163, 1896.

It will be noted that the dissolved matter, both organic and inorganic, fell off markedly after the first extraction, which was larger because of the matter in solution in the soil water. Later extractions were smaller, supplied largely from the substances held by adsorption, which gradually diffuse into the water extract as the tendency to maintain equilibrium of the solution overcomes the adsorptive action. With the removal of the adsorbed substances, the equilibrium between the soil particles and the surrounding solution is disturbed, solvent action is increased, and more material gradually passes from the soil into the solution. In this way the solution and continuous body of extractive is maintained.

246. *Other factors influencing extraction.*—For purposes of soil analysis, the quantity of water used for extraction must be placed at some arbitrary figure, and this is open to the objection that it does not represent accurately the soil-water solution. Analyses of soils of different types are not comparable, and the water extract cannot be considered as measuring the concentration, or even the composition, of the solution existing between the root hair and the soil particles. However, for studying some of the changes which go on in the soil and which are detectable in the soil-water solution, the practice may be followed to advantage.

247. *The soil solution in situ.*—It has already been pointed out that the interstitial spaces of any soluble soil contain more or less water all the time; that there is a constant tendency for this water to assume the capillary condition owing to the gravitational movement of free water; and that the normal exosmosis of moisture from the soil tends to reduce the capillary film to the condition of hygroscopic water (p. 132). As the movement

of free water is comparatively rigid and that of soil-water rather relatively slow. The soil moisture supply is usually somewhere between the point of hysteresis and free water. In this condition each particle or aggregation of particles is enveloped in a thin moisture film, and this film water is constantly in motion although the movement is rather slow.

Salts are more or less soluble in pure water; and in soil water, changed as it always is with certain acids, they are still more readily soluble. Consequently the moisture films constantly tend to approach a state of equilibrium with respect to the water-soluble matter in the soil particles. If plants are entirely dependent for their mineral nutrients on the supply in the soil-water solution, the strength of the solution becomes an important matter. The supply of mineral nutrients for higher plants will be discussed later (pp. 320). Even if the plant itself has no influence on the supply of mineral nutrients that go into solution, the quantity of food that it finds in the soil solution already prepared for its use must constitute an important factor in its growth.

Unfortunately there is no adequate method of measuring the strength of the solution. Attempts have been made to remove this solution from the soil, but it is altogether unlikely that the analyses of the liquid obtained represent the composition of the soil solution, because of the very small quantity of the liquid available for analysis and also because of the uncertainty that the sample obtained was representative of the soil solution.

Mr. Jowett for obtaining a soil solution "is assisted by *Plasma and Medicine*" to sample the soil solution

¹Jowett, Emma J., and Watson, Alice R., *The Nutrition of Plants*, 1916, 2d ed., 7th A., New York, pp. 55, pp. 14, 1917.

involved the use of centrifugal motion, which developed a force of two or three thousand times that of gravitation. When the soil contained a rather large quantity of capillary water, a small amount of it could be removed in this way.

Another device, by Briggs and McCall¹ consists of a close-grained, unglazed, porcelain tube, closed at one end and provided at the other with a tubulure, by which it can be connected with an exhausted receiver. This tube is inserted and tamped in the soil. If the moisture content of the soil is sufficient to reduce the pressure of the capillary water surface in the soil to less than the difference between the pressure inside and outside of the tube, there will be a movement of water inward. This water may be collected and analyzed.

More recently Van Slichtenhorst has used another method to obtain the soil solution.² He replaces the soil water by means of paraffin in a liquid state, at the same time subjecting the soil to suction on a filter. The displaced water is considered to represent the soil solution.

244. *Concentration and concentration of the soil solution*.—It has generally been held that because some soils are more productive than others, and because fertilizers containing soluble salts frequently increase the yields of crops, the soil solution in the better-yielding soils is more concentrated, at least as regards plant nutrients, than it is in the poorer soils. The argument is, of course,

¹ Briggs, T. F., and McCall, A. G. An Artificial Method for Isolating Capillary Movement of Soil Moisture. *Bulletin*, N. S., Vol. 25, pp. 586-590. 1904.

² Van Slichtenhorst, E. H. T. Methode zur Gewinnung der Nahrungssubstanz. *Ann. L. Landw.*, Band 91, 59-62. 1902.

based on the assumption that, other things being equal, plant growth is a function of the concentration of the plant nutrients in the soil solution. According to this conception, increased or decreased soil fertility is reflected in the composition and concentration of the soil solution, and this in turn in crop yields. The soil solution is therefore a variable quantity, and to some extent at least, within the control of man. An elaborate explanation for the requirements of the soil solution has been worked out by Van Bormaal and his school.

268. Variability in composition and concentration of the soil solution.—The process of rock weathering has, according to Van Boven¹, Bills² and others, resulted in deep-seated chemical changes in some of the mineral constituents of the soil, whereby there are formed complex colloidal aluminates which, in the form of gels, cover the surfaces of the soil particles. These colloidal complexes may contain iron, aluminum, calcium, magnesium, potassium, phosphorus, and other substances, which are absorbed from the different strata of the soil or are washed and deposited in quantity on the concentration of the solution from which they are absorbed. They dissolved in the soil solutions, whose composition changes with every change in the concentration of the liquid solution that comes in contact with them. This solution of the colloidal complexes in the soil water with which they come in contact is especially different from that of the

¹Von Demme, J. M. Beiträge zur Kenntnis der Fäulnisprodukte der Stärke in Ton, Vollkornmehl und Mehlspeisen. *Arch. f. experiment. Chemie*, Band 52, S. 285-294, 1906.

Witz, W. Ueber die Gegenstände Bezeichnung: Cal-
kulation. Die deutsch. ökon. Gesell., Bonn
R. 1895-1900. 2004.

pure minerals, as they are not free dissolved entities (ions). The organic matter in the soil with another class of colloidal matter; so that, in the opinion of Van Buren (1934),¹ the colloidal character of humus (solid humus form, in various proportions, a mass of colloidal complexes that control the composition of the soil solution. The colloidal condition of this material is readily decomposable under variations in temperature and concentrations of solutions, and would therefore be in a state of constant transition in the soil.

This conception of the soil surface would account for changes in the composition of the soil solution due to the application of soluble fertilizers, and would also explain the continued effect of such fertilizers on the theory that they are absorbed by the colloidal surfaces and released in the soil solution tends to become more clear.

A somewhat different view has been taken by Whitney and Cameron, who hold that the composition and composition of the solution in all soils is practically the same. Their conception, according to a recent paper by Cameron,² appears to differ from that of Van Buren in assuming that the soil water is in contact with the soil particles for such a short time that the quantity of matter that goes into solution is too slight to bear any relation to the total quantity of soluble matter in the soil. The soil solution does not come into equilibrium with the soil mass, nor even approximate such a condition. The

¹Van Buren, J. M., *Die Zusammensetzung der Ackererde*. Leipzig, Von Vieweg, Band II, Seite 245-252, 1934.

²Cameron, F. R., Composition of the Soil Solution. *Original Communications, Eighth International Congress of Applied Chem.*, Vol. 2, pp. 47-48, 1932.

plants being studied in all soils, it follows that the rate for growth of plants of different soils seems to relate to the supply of soluble nutrients, but must be due to other factors. Heavy soluble fertilizers increase plant growth, not by supplying a greater quantity of plant nutrients, but through other effects on the soil—as, for instance, their favorable influence on tilth, or through the destruction of toxic matter.

220. *Discussion of the theories regarding soil solution.* The difficulty in securing a true sample of the soil solution as it exists in situ complicates any attempt to ascertain how these theories compare with the actual condition of the soil solution. A number of attempts have been made to throw light on this subject, but none of them obtained a definite solution to definitely prove the correctness of either theory. The evidence, so far as it goes, indicates that the water content of soils differs in concentration in different soils, and in comparison, under some conditions, by large and constant applications of soluble fertilizers. There can be no doubt, however, that plant growth in properly balanced nutrient solutions increases with the concentration of the solution up to several thousand parts to the million, as has been demonstrated by many experiments.

One rather convincing experiment may be quoted. Hall, Henselby, and Henderson¹ analyzed the water extract from certain plants on the Rothamsted Experimental Station farm, the fertilizer treatment and the yields of which had been recorded for a long time of years.

¹Hall, A. G., Henselby, H. A., and Henderson, W. M. *The Soil Solution and the Absent Constituents of the Soil*. Philosoph. Trans. Royal Soc. London, Series B, Vol. 201, pp. 175-220, 1902.

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Complete analysis of the soil from the several plots were also made:

Yields of Corn, and Capacities of Soil and Water, Reflect of Soil, in Following Representative Figures: ¹
 Feet

| | Total moisture per foot | Chemical Analysis | | Water Content | |
|--------------------|----------------------------------|-------------------|----------|---------------|------------|
| | | PH | SG | PH | SG |
| | | (normal) | (normal) | (0 to 10%) | (0 to 10%) |
| Unmanured . . . | 1.978 | 6.000 | 0.718 | 0.000 | 3.60 |
| 34 + 190 . . . | 2.072 | 6.772 | 0.740 | 3.300 | 3.80 |
| 34 + 750 . . . | 2.286 | 6.300 | 0.757 | 8.800 | 20.25 |
| Complete fertility | 5.087 | 6.382 | 0.828 | 4.005 | 24.81 |
| Water moisture . . | 5.694 | 6.176 | 0.842 | 6.400 | 26.65 |

A similarly treated set of plots, which had been planted to another crop and analyzed to more than, gave similar results. It is a very striking example of the effect of long-continued treatment of the soil with certain fertilizer on the composition of the water extract. The subject, however, must be investigated further, as it is of fundamental importance to a knowledge of the properties of soils.

CHAPTER XVI

THE ADSORPTIVE PROPERTIES OF SOILS

In the brown water extract from manure is filtered through a clay soil not containing soluble silicates, the filtrate will be nearly colorless. Many solutions of dyestuffs are affected in the same way. Solutions of alkali or alkaline earth salts are more or less modified by this operation, the bases being retained by the soil to a greater extent than are the acids. Thus, when a solution of the silicate, molybdate, or chloride of any one of these bases is filtered through the soil, a part of the base is absorbed by the soil, while most of the acid passes through in the filtrate. If these bases are in the form of phosphates or silicates, not only the base is absorbed, but the acid as well.

III. Substitution of bases.—Associated with the absorption of the base from solution, there is frequently a more or less base from the soil, which combines with the acid in the solution and appears in the filtrate as a salt of that acid.

When absorption takes place from solution, the base is never entirely removed, so neither how dilute the solution may be. A dilute solution of potassium chloride filtered through a soil will produce a filtrate containing some calcium, magnesium, or sodium chloride, or all these salts, and some potassium chloride. The more dilute the solution, the larger will be the proportion re-

taired, but the less the total quantity absorbed. Fries¹ treated 100 grams of soil with 200 cubic centimeters of a solution of potassium salts, and found that the potassium of different soils was retained in different proportions, and that the stronger solutions held relatively less than the weaker, while more potassium was recovered from the stronger solutions.

| Percentage of Potassium | % Potassium | % Potassium |
|--|-----------------------|-----------------------|
| | (Given Salt Absorbed) | (Given Salt Absorbed) |
| KCl | 0.0128 | 0.0100 |
| K ₂ CO ₃ | 0.0382 | 0.0098 |
| K ₂ SO ₄ | 0.0247 | 0.0034 |

The same bases are not always absorbed in the same proportion by different soils; one soil may have a greater absorptive power for potassium, while another may retain relatively more ammonium. They seem to be interchangeable, so any ammonium base may be released by another in solution. The absorptive power of a soil for certain bases is affected in the composition of the drainage water from the soil. The composition of the drainage water varies with different soils, and a soluble fertilizer applied to one soil will have a different effect on the composition of the drainage water than if applied to a different soil. This is well illustrated from Lyman's experiments by Gerbich² at Bonnberg. Several soils were used,

¹Fries, R. *Ueber die Absorption von Kali durch Acker- und Garten-erden*. Landw. Vers. Stat., Band 3, Seite 115-116. 1893.

²Gerbich, Dr. *Ueber die durch Ackererde des Bodens ausgeschiedene Menge Wasser und Nährstoffe*. III. Landw. Vers. Stat., 1894, Seite 271-282. 1901.

one of each being fertilized and one unfertilized. The fertilizers were 1.2 meters deep and contained 6 cubic yards of soil. The drainage water was caught and analyzed for five years. The first year there was no crop, the second year potatoes were grown, the third only and the fourth rye. The following results were shown:—

ANALYTICAL CONCENTRATIONS OF DRAINAGE WATER IN FIVE YEAR MEANS

| Soil. | Treatment. | Total Fertilizer | Ammonia Nitrogen | Urea Nitrogen | As Fertilizer |
|-----------------------------|--------------|---------------------|---------------------|------------------|------------------|
| Mar. soil. | Fertilized | 23.7 | 26.8 | 1.7 | 35.2 |
| | Unfertilized | 5.0 | 6.2 | 4.7 | 35.2 |
| Lumpy sand low in humus | Fertilized | 35.5 | 26.1 | 0.4 | 25.1 |
| | Unfertilized | 20.9 | 20.4 | 1.6 | 8.5 |
| Sandy loam high in humus | Fertilized | 67.8 | 64.6 | 1.1 | 70.3 |
| | Unfertilized | 65.5 | 66.1 | 5.4 | 47.4 |

Absorption will not proceed so far undisturbed as soil. A soil will cease to absorb any particular substance after a certain quantity has been taken up. This quantity will vary with every soil. Clay and loam soils have greater absorptive power than sandy soils. This difference, both as to amount and as to rate of absorption, is well shown by the following curves adapted from Schröder and Palocz.¹

¹Schröder, O., and Palocz, O. H. The Absorption of Phosphorus and Potassium by Soils. U. S. D. A., Bur. Soils, Bul. 22, 1903. See also Schröder, O. T., and Palocz, O. H. The Mutual Exclusion of the Soil Solution. U. S. D. A., Bur. Soils, Bul. 23, pp. 45-66, 1903. Palocz, O. H., and Schröder, O. H. Absorption by Soils. U. S. D. A., Bur. Soils, Bul. 22, 1903.

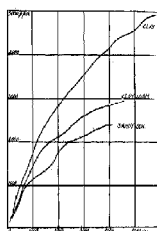


FIG. 31. — Curves showing the character of P_2O_5 in parts in a million by volumetric analysis, which is equivalent to P_2O_5 in parts in 100 parts in a million of P_2O_5 . The values of the percentage used as the ordinate.

Note. — The law which appears to govern absorption of phosphorus and potash by the soil may be expressed mathematically as follows: —

$$\frac{dy}{dx} = K(x - y)$$

in which K is a constant, x the maximum quantity possible for the soil to absorb, and y the quantity actually fixed when a volume of the solution has percolated through.

A short discussion of the mathematics of this law may be found in the following publications: HENRIQUE, G., and DILLON, G. H. *The Absorption of Phosphorus and Potassium*, by Soil. U. S. D. A., Bur. Soils, Bul. 28, pp. 25-28, 17-26, 1904.

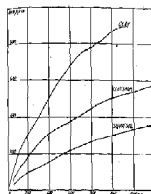


FIG. 16.—Curves showing the absorption of K_2A by a solution in a solvent contained 500 parts to a million of E . The values of the penetration and so the diffusion.

183. *Time required for absorption.* The amount of absorption depends on the time of contact between the soil and the solution. While a large part of the dissolved ion is taken up in a short time after being placed in contact with the soil, the maximum absorption is effected only after a considerable period. Arsenious, according to Wray, reaches its maximum absorption in half an hour; while Rosenbery and Stokeman¹ found that phosphorus required twenty-four hours to reach the same degree of absorption.

¹ Rosenbery, W., and Stokeman, P. "Über die Verhältnisse der Aufnahme von Phosphor vom Ammoniumsalz, Ammoniumphosphat." *Ann. f. Landw. Vers. Wes.*, Band 3 (Der neue Weinbau), Leipzig, Seite 25 et. 1893.

This, however, has no significance so far as danger from loss of a soluble fertilizer constituent is concerned, since water, even after a heavy rain, would not pass so quickly through the soil that absorption would not take place, except possibly in the case of soil of a very coarse texture. The depth through which the substance is distributed in the soil may, however, be influenced by the time required for its absorption. Ordinarily fertilizers do not penetrate very far into the soil. Deneken and Broun¹ have investigated the rate and distance of penetration of certain soluble salts in soil, and find that a total rainfall of ten inches is not sufficient to carry down sodium nitrate in a sandy soil to a depth of eight inches.

355. Absorbability of certain absorbed substances.

Although bases once absorbed may be easily displaced by other bases, it is difficult to transfer them from the soil into pure water. Pabst² treated 100 grams of soil with 550 cubic centimeters of water containing potassium chloride, of which 0.2714 gram of KCl was absorbed. The soil was then leached with distilled water, using 1.5 cubic centimeters of water daily for ten days. At the end of that time 0.0675 gram of KCl had been removed, or at the rate of 25/100 parts of water to one part of KCl dissolved from the soil. Henschberg and Steinhart³ found that it required 18,000 parts of water

¹ Deneken, A., and Broun, G. *Sur la Penetration des Sels dans le Solon*. *Ann. Agric.*, Tome 26, pp. 401-403, 1911.

² Pabst, R. *Ueber die Absorption von Kali durch Ackererde*. *Landw. Vers. Stat.*, Band 1, Seite 112-124, 1903.

³ Henschberg, W., and Steinhart, E. *Ueber die Verhinderung der Auenverwässerung durch Wasser und Ammoniak*. *Ann. f. Landw., Wein-Pflanzen, Band 1* (Vorjahr 1914) *Landw. Jahrbuch*, Seite 37-47, 1915.

to involve one part of absorbed ammonia from the soil.

325. *Influence of size of particles.*—The surface area of the soil particles determines to some extent the amount of substances absorbed. For this and other reasons, a fine grained soil absorbs a greater quantity of material than a coarse-grained soil. In fact, it was early shown by Way¹ that the phenomenon of absorption is largely a function of the clay, clay, and humus of the soil.

326. *Causes of absorption.*—A number of causes have been assigned for the absorption of substances by soils, and there can be no doubt that the phenomenon is not due to any one process. Several distinct causes are now very generally recognized, while others that have been suggested may have a part in the result.

326. *Ionization.*—As the result of his careful researches on absorption of salts, Way concluded that the property of absorption, or fixation of bases, runs largely with the hydrated silicates of aluminum, containing calcium or magnesium and one of the alkali metals, these compounds being known as zeolites. He prepared artificially a hydrated silicate of aluminum and sodium, and found that by treating this with a solution of a calcium salt he could replace most of the sodium, obtaining thereby a silicate of aluminum, calcium, and part of the zeolite that was originally contained in the silicate. The remainder of the sodium could be replaced by potassium from a potassium salt, likewise by magnesium and ammonium.

¹Way, J. W. On the Power of Soils to Absorb Ammonia. *Phil. Mag. Ser. 4*, London, Vol. 11, pp. 223-229, 1856. On the Power of Soils to Absorb Ammonia. *Ann. Mag. Nat. Hist. Ser. 4*, London, Vol. 11, pp. 122-143, 1858. Also On the Influence of Zeolites on the Absorption Properties of Soils. *Phil. Mag. Ser. 4*, London, Vol. 15, pp. 461-465, 1858.

Wey found further that exposure to a strong heat destroyed the absorptive properties of these substances, and also treated with strong hydrochloric acid. In all these respects the absorptive properties of the soil coal of the various minerals.

237. *Chapman*.—Richards¹ experimented with the natural soils of various minerals, and found that he could produce satisfactorily by means of the proper salt solutions. In column I of the table below is given the composition of the substance used for the experiment; in column II is given the composition after treatment with a solution of sodium chloride; and in column III the composition after the residue is further treated with a solution of ammonium chloride:—

COMPOSITION OF CHARACTERS OF SOILS AND THEIR TREATMENT WITH SODIUM CHLORIDE AND AMMONIUM CHLORIDE

| CHARACTERS | I | II | III |
|--|------|------|------|
| SiO ₂ | 47.6 | 49.1 | 51.5 |
| Al ₂ O ₃ | 20.7 | 21.3 | 22.3 |
| CaO | 10.4 | 6.7 | 4.2 |
| K ₂ O | 0.7 | 0.9 | 0.6 |
| Na ₂ O | 0.6 | 5.4 | 0.6 |
| H ₂ O | 20.3 | 22.1 | 14.9 |
| Fe ₂ O ₃ | 0.6 | 0.0 | 0.9 |

The analyses were evidently made at the expense of sodium in the compounds, both when treated with sodium and when treated with ammonium salts in their equivalent quantities. These and subsequent

¹ Richards, R. *Ueber die Eigenschaften von Mineralen*. Leipzig und Berlin: J. Neumann, Neudamm, 1888. *Abhandl. Band 2*, Seite 100-105.

pointed to by numerous investigators have been rather widely accepted as indicating that the soilites are at least partly responsible for the absorptive properties of soils. It has been shown further that the absorptive power of a soil is more or less proportional to the quantities of acid-soluble silicates it contains. The soilites being rather easily soluble in strong mineral acids, it is held that the bases so neutralized are more readily available to plants than in most combinations found in the soil, and yet are not easily leached out of it.

334. *Presence of soilites questioned.*—On the other hand, analyses have never been definitely proved to be present in soils. Merrill¹ has attempted to show that they cannot be of wide occurrence in soils, but neither their absence nor their presence has been demonstrated. Since the time when Way first published his researches in 1840, the acidic constituents of the soil have generally been held to be largely responsible for its absorptive power for bases.

335. *Absorption of phosphoric acid.*—It has already been said that although hydrochloric, sulfuric, and nitric acids are not absorbed by soils, except in small quantities, phosphoric acid is absorbed and retained in an almost insoluble condition so far as extraction with water is concerned. That this absorption cannot be due to soilites is generally conceded, and has recently been demonstrated, for example at least, by Rosenow and Wagner,² who in a carefully conducted experiment

¹Merrill, R. P. *Soils, Rock Weathering, and Soils*, pp. 332-337. New York, 1906.

²Rosenow, R., and Wagner, O. *The Absorption for Phosphorus of Soils "Soilites"*. *Proceedings, Amer. J. Land.*, Vol. 10, pp. 222-226. 1917.

with this soil— which is an ammonium gel containing potassium, calcium, aluminum and silicic acid— found that there was no absorption of phosphoric acid from a neutralized solution of ammoniacal phosphate or from a solution of disodium phosphate at various degrees of concentration.

101. *Formation of insoluble phosphates.*—The relative of soluble phosphoric acid in soils may be easily accounted for by the fact that there are present in all soils hydrated ferric oxide and hydrated silicates of aluminum, and frequently calcium carbonates, with which substances phosphoric acid in solution would naturally form compounds insoluble in water. Iron and aluminum phosphates are practically insoluble in water containing carbon dioxide or weak organic acids such as might be present in soil water. Calcium carbonate forms with a soluble phosphate fertilizer some disodium phosphate, the solubility of which in soil water is much greater than the iron and aluminum phosphates. This is one of the advantages of keeping a soil well supplied with lime if a superphosphate fertilizer is to be used. Even the trisodic phosphate, although less soluble than the dihydrate, is more readily soluble than the iron and aluminum phosphates. As lime has a tendency to move downward in soil, and as phosphoric acid is retained in the place depth when added as a fertilizer, it is important that the application of lime be sufficiently frequent to keep the pad of the soil in a condition to form the lime phosphates.

Cameron¹ has suggested that the absorption of phosphoric acid is probably due to the formation with lime or ferric oxide of a solid solution, which might account

¹ Cameron, P. E. *The Soil Solution*, p. 51. *Science*, 1911.

for the availability of phosphorus is only to which a superphosphate fertilizer had been applied many months previously. It might explain also the availability of a superphosphate on soils devoid of carbonic carbonate. Although such availability is always less than when the carbonate exists, it is greater than would be accounted for by the solubility of ordinary iron phosphate.

321. *Absorption*.—There is a physical fraction, termed *absorption*, due to the concentration of the soil solution in immediate contact with the surface of the particles. The phenomenon is familiarly exemplified in the clarifying effect of the chemical filter. This process results in the retention, in fine-grained soils, of considerable soluble material that would otherwise be washed out. In the case of silicates, which are not retained by the soil, absorption is an important factor (par. 211). If a solution of a known quantity of nitrate of soda is added to a clay soil, and an attempt is then made to extract the nitrate from the soil with distilled water, it will be found impossible to remove a very appreciable proportion of the nitrate added. While absorption probably does not account for all the nitrate retained, there can be no doubt that it plays an important part. Nutrients held in this way are readily available to the plant, whose root hairs come in contact with the soil particles. It is not impossible that other fertilizer constituents are held by the soil in this manner.

322. *Absorption by colloids*.—According to Van Baecken, who has made a very exhaustive study of this

¹Van Baecken, J. M., *Die Absorptionseigenschaften und die Abhängigkeitsverhältnisse der Adsorption*. *Landw. Vers. Stat.*, band 25, Seite 81 (26). 1888. Also, *Die Absorption*, 340 p. London, 1910.

colloidal absorption by soils is, without doubt, largely due to the presence of colloidal matter which exerts an adsorbent action for water, gases, solutes, and solids in suspension. The colloidal matter in soils that contribute to their absorptive properties are the following:—

- (1) remains of plant and animal tissues;
- (2) humous substances;
- (3) colloidal iron oxide;
- (4) colloidal siliceous acid;
- (5) amorphous colloidal silicates that have been formed through weathering.

Van Bemmelen also credits crystalline silicates with adsorbent properties, although he does not consider this their action is very important. Adsorption is brought about also by true chemical combination of soil compounds with substances in solution, by which certain of the cations or anions in solution are chemically combined and remain in the soil in a very difficult soluble condition.

343. *Adsorptive properties of colloidal matter.*—Among the products of rock weathering there have been found in soil numerous substances that are of the nature of colloidal gels. These, with the other colloidal matter, are contained in the very small particles that remain for a long time in suspension when soil is stirred up in water. These colloids are complicated by many acids, and by some bases and salts. This is especially true of the material that is dialysable. Some of these again go into solution on being treated with water, while others remain insoluble until they undergo molecular change. Many colloids form hydrates with soil water. These hydrates are not ordinary chemical compounds. They dry very slowly. They absorb water in varying quantities, and

in certain definite proportion to the crystallinity in the process of crystallization. The more water absorbed by colloids, the less firmly is it held in coagulation. Therefore it is easier to regenerate the water when a large quantity has been taken up, and in the amount decreases it becomes more difficult to drive it off.

Another property of colloidal matter is that when it is separated from solution it comes down with it other substances in the solution from which it is precipitated. If, on the other hand, the colloidal matter has been precipitated in a pure state, it absorbs substances from solutions with which it remains in contact for some time. The substances taken up in this way are not chemically combined, but substances that will chemically may be absorbed.

The combinations produced by absorption are such that it is possible to knock out the combined substances, which are generally held in the water of the gel. The following example of one kind of absorption is given by Van Bemmelen:¹ ten grams of a hydrate having the composition $\text{SiO}_2 \cdot 4.5\text{H}_2\text{O}$ shaken with 100 cubic centimeter solution of 20 molecular equivalent Na_2O , will absorb 0.8 to 1.1 molecular equivalent of the dissolved substance. The absorption in this case was as if the silica had been diluted with 4.2 to 5.8 cubic centimeters of water. As the amount of gel water in 10 grams of hydrate of SiO_2 is about 5 cubic centimeters, the assumption may be made that the dissolved substance is taken up in equal concentration by the gel water. Ten grams of hydrate of SiO_2 shaken with 100 cubic centi-

¹Van Bemmelen, J. M. *Die Absorptionen/Kolloide und die Lösungsvermögen der Substanzen*. London: Van Nostrand, New York, 1908.

water solution of 50 molecular equivalent, 6.1×10^{-3} that is, 24 times the concentration of the former solution—dissolve 24 times as much, or 24 to 1.5 molecular equivalent. This applies also to concentrations five times stronger than the first mentioned above, but beyond that the relation is not so simple. It serves, however, to illustrate the manner in which the absorption takes place from dilute solutions.

564. Selective absorption.—A selective absorption is very common, especially from solutions of salts having weak acids, a greater fraction of the bases taking place than of the acids. Dissociation of the salts takes place in the solution, the bases being absorbed, in consequence of which further dissociation occurs; and this proceeds until an equilibrium is established between the absorbing and ionizing power of the colloidal material and the reverse action of the water and reacting acids. In this way the absorptive power decreases as the amount absorbed becomes greater.

The colloidal material possess the property of absorbing a certain base when presented to it in solution, and contributing in return a chemically equivalent quantity of some other base. Potassium is most freely retained in the soil and most strongly withdrawn from solution, with an exchange of a chemically equivalent quantity of calcium, sodium, and magnesium, which passes into the solution. If a soil is treated with a solution of potassium, ammonium, sodium, or calcium salts of rapid concrete salts, the concentration of the solution in the end is 40% for the potassium than for the magnesium, and 125% for the magnesium than for the sodium and the calcium, because the potassium is most strongly bound in the colloidal material, while the calcium and sodium are least

in. In other words, the action of a sodium salt in solution on the absorbed potassium combination is less than the action of a dissolved potassium salt on the absorbed sodium combination. Thus it seems about that under similar conditions of temperature, volume, and concentration of the solution, the quantity of sodium or of sodium or of ammonium that goes into solution upon colloidal silicates treated with a solution of a potassium salt is greater than the quantity of potassium that would go into solution if the same silicates were treated with a solution containing the same of any of these other bases.

26. Absorptive power of colloidal silicates.—The quantity of a substance that a certain weight of a colloidal silicate can absorb increases with the strength of the solution of the substance presented for absorption, however the final solution can remain stronger and consequently its solvent power for that particular substance is less. The point of equilibrium between the fixing power of the solid and the solvent action of the solvent therefore varies with the strength of the solution.

The nature of the acid with which a base is combined likewise has an influence on the quantity of the base absorbed. A base combined with a weak acid is absorbed in greater amount than the same base combined with a strong acid. This is presumably because the stronger acid remaining in solution has a greater solvent action.

27. Absorption by colloids versus absorption by solution.—The early conception of the phenomenon of fixation in soils was naturally a chemical one and was founded on the chemical knowledge of that day. The fact that the substitution of bases in the solutions passed through the soil was in chemically equivalent quantities,

placed it in the soil that was known regarding chemical reactions. Zeolites were found to possess absorbing properties of a similar nature to that of silica in solution, a characteristic of which is the substitution of bases and the appearance in solution of the mineral base in combination with the acid of the original salt. It was a natural conclusion that true natural zeolite must in soil and that the absorbing properties of soil are due to their action.

Many years later, when the principles of physical chemistry had been applied to the study of colloids, it was shown that absorbing properties are possessed by certain colloids similar to those characteristic of soils. Zeolites have never actually been isolated from any soil. This fact has always occasioned some doubt as to the hypothesis to which their properties have given rise. Colloids, on the other hand, are well known to occur in soils, but the exact nature of soil colloidal matter is not well understood; consequently there is considerable indefiniteness about the extent of their absorbing function, and even *van der Waals* grants the crystalline a part in this phenomenon.

The *colloid* hypothesis furnished an explanation for the form in which the available plant-food materials of the soil are held. On it is largely based the idea that the solution of a soil in strong hydrochloric acid represents the nutrients that are available to plants. The nutrients that go into solution are held to be the available cationic acid and the bases with which it is united. The fact that such treatment largely destroys the absorbing properties of a soil is taken as a proof of this. It would, however, serve equally well as an argument in favor of cationic absorption, on the colloidal condition of the

system would be destroyed by the same treatment. On the whole, the evidence appears to be in favor of the dominance of colloidal absorption rather than crystalline absorption by soils, with its important function in conserving soluble fertilizers and retaining a supply of plant nutrients in a more or less readily available condition.

897. *Absorption by organic matter.*—The partially decomposed organic matter in soils, especially that part which has undergone such transformations as to form humus (see 19), has an absorptive power. Soils rich in humus, without doubt, owe much of their fertility to the retention by that constituent of a large supply of readily available plant-food material. Many precise soils that have been reduced in productivity under cultivation respond to the application of organic matter in a remarkable manner. Hence it there well seems to be the chief sources of readily available plant-food material.

Van Bemmelen¹, who has studied these compounds, states that with liquid colloidal humous compounds containing mucosins, pectins, gelatins, and other substances, as well as iron salts. A part is soluble, in fact, soluble compounds with silica, but the principal part is insoluble. Some of these latter compounds are of a colloidal nature and of changing composition. The soluble nature is easily precipitated by acid solution and carries down with it bases from the solution. Absorption of bases also takes place from solution, with substitution of one base for another. Potassium is more strongly held in mechanical than in calcium or magnesium. Bases are removed, however, only from salts of the weaker acids.

¹Van Bemmelen, J. M. *Die Absorption*, Bohn 133-141, Dresden, 1921.

519. Absorption of water vapor and of gases by soils. — Hygroscopic water in soils has already been discussed (pp. 535, 536, 538). It need merely be mentioned here that there is a close relation between the absorptive power of a soil for water vapor and for gases. Soils having a high content of humus and composed of very fine material are likely to have great absorptive properties for both vapor and solution.

In a similar way soils absorb gases. The denitrifying property of soil is well known. Decomposing organic matter is rendered ineffective by covering it with soil. Gases produced in the processes of decomposition are largely absorbed by the soil. The fertility of the soil may be increased by the absorption of certain gases.

520. Absorption of ammonia. — Ammonia, which exists in minute quantities in the air, is absorbed by soils, and also when given off by decomposing organic matter in the soil. As all nitrogenous organic matter may eventually form ammonia when decomposed, the ability of the soil to absorb it is very important. Grasses alone will absorb only a very small quantity of ammonia, while a clay soil will hold practically all that is likely to be produced by the decomposition of the organic matter incorporated in it.

521. Absorption of carbon dioxide. — Carbon dioxide is absorbed by soils to a very considerable extent, and this also adds to the productivity of soils, since it aids in their decomposition. The supply of carbon dioxide comes from decomposing organic matter and from plant roots. As will be explained later, the soil air always contains a considerable supply of this gas, and its constant desorption and absorption is constantly going on. It forms soluble bicarbonates with the silicates and laves of soils, producing a readily available plant-food material.

51). Absorption of nitrogen and oxygen. Nitrogen is absorbed by soils to a greater degree than is oxygen. The latter probably is of greater importance to soil fertility, as its absorption is accompanied by oxidation of other absorbed gases. Because of their absorptive properties and their great surface area, soils have strong oxidizing power.

The absorption of gases by soils is largely an absorption phenomenon, the gases being condensed on the surface of the particles. Von Tobolsky¹ has shown that the absorption is greater, the finer the particles of soil, but this increase is not directly proportional to the increase in surface, large particles apparently having a greater absorptive power than their surface area would indicate.

52). Relation of temperature to gas absorption. The temperature of the soil influences its absorptive properties for vapors. As the temperature increases the absorption becomes less. Hilgard² does not find this to be the case (p. 110). He exposed soils to a controlled atmosphere and found that they absorbed more moisture at high than at low temperatures. In his conclusions, however, he is doubtless in error. All the work previous to his gave a directly contrary result, and a more recent investigation by Fettes and Gallagher³ confirmed the work of the earlier investigators.

¹Von Tobolsky, A. T. *Thermodynamik der Adsorption*. Untersuchungen und die Thermodynamik der Bodenabsorption. Russk. u. Engl.-Folge, Band IX, Heft 163-225, 1912.

²Hilgard, H. W. Soils, pp. 105-106. New York, 1908.

³Fettes, H. K., and Gallagher, P. B. *Absorption of Gases and Vapors by Soils*. U. S. D. A., Bur. Soils, Bul. 33, pp. 21-31, 1918.

273. Relation of absorptive capacity to productivity.—The absorptive capacity of a soil is not so much a measure of its immediate as of its permanent productive power. It is well known that a very sandy soil responds quickly to the application of soluble manures, but that the effect is confined mainly to one season; while a clay soil, although not so quickly responsive to fertilization, shows the effect of the application much more markedly the second or the third year than does the sandy soil. *Ammonium*, which is largely shown in sandy soil, holds the absorbent material in a very readily available condition, while absorption by *ammonia* compounds renders these substances somewhat less readily available. There are also other reasons why the sandy soil is more responsive. King¹ is working with eight types of soil from different parts of the United States, found that those soils removing the most potassium from solution gave the largest yield of crops. It would not be permissible, however, to adopt this test as a method for determining productivity in soil.

274. Ammonium as related to drainage.—The drainage water from cultivated fields in humid regions, and to a less extent in arid and semi-arid regions, except when irrigation is practiced, carries off very considerable quantities of plant-food material. The loss of this material is due to the operation of the various natural disinfectative agents on the soil mass, and to the application of fertilizing materials in a soluble form. The various absorptive properties stand between the natural solubility of the soil and the tendency to loss in drainage, and hold, in a condition

¹ King, R. L. *Indicators of Farm Yield* January 1924, Yale and open the Wisconsin State of Soil, p. 26. Madison, Wisconsin, 1926.

in which they may readily be used by the plant, those materials which would otherwise be lost.

54. *Substances usually omitted in drainage water.*— However, some material is always lost in drainage water, of which, among the bases of the soil, those most likely to be lost are calcium, sodium, magnesium, and potassium; and of the acids, carbonic, nitric, sulfuric, and hydrochloric. Nitric acid and lime undergo the most serious losses. The former may be retained to a great extent by keeping grass growing on the soil during all the time that nitrification is going on, and if the crop does not mature, for if for any other reason it is not desired to harvest the crop, it should be plowed under to return the nitrogen to the form of organic matter. A crop used for this purpose is called a catch crop. It is used under commonly as a catch crop, as it continues growth until late in the fall and resumes growth early in the spring, conserving nitrates whenever nitrification is likely to occur, and it may then be plowed under to prepare the land for another crop. Rye also has the advantage of small cost for seed.

The loss of calcium cannot well be prevented, and the use of commercial fertilizer always greatly increases such loss. The only remedy is the application of some form of calcium to the soil.

55. *Drainage records at Eastman.*— Drainage water from a series of plots at the Eastman Experiment Station, which have been measured in various ways and planted to wheat each year since 1902, have been analyzed at certain times, and the results of these analyses, as compiled by Hall,¹ give some idea of the loss

¹Hall, L. D. *The Book of the Doctored Experiment*, pp. 227-229. New York, 1905.

of salts from calcareous soils. The drainage water was obtained from the tile drains, a line of which extended under each plot from one end to the other and opened into a ditch, so that the water could be collected when desired. The analyses are shown in the table on page 871.

Ammoniacal nitrogen in the drainage water is very small in quantity, but nitrate nitrogen is present in quantities sufficient to make the loss of same concern. The use of sodium nitrate occasioned the greatest loss of nitrogen, while ammonium salts and farm manure contributed nearly as much. From forty to fifty pounds of nitrogen to the acre may be lost annually in this way; this amount would have a commercial value of eight or nine dollars.

276. *Drainage records at Housberg.*—It is not always the case that a manured soil loses more fertility material than an unfertilized one. Gerlach's reports experiments in soil made at the Rönneberg Institute of Agriculture, on the results of which his soils, when naturally fertilized, yielded larger crops and had in the main less nitrogen and lime in the drainage water than the same soils unmanured. The loss of potash was slightly greater from the manured than from the unmanured soils. Apparently the stimulation that the plants received from the fertilizer enabled them to make such a good growth that they absorbed more soluble nitrogen and lime in excess of the unfertilized plots than was solved in the fertilizer, and used as such potash.

¹ Gerlach, M. *Ueber die durch Sickerwasser dem Boden entzogene Menge Phosphor und Kaliumstoffe*. *Mon. Landw. Statist.* 29 Jahrgang, Heft 15, Seite 377-403. 1910. *Ann. Untersuchungen über die Menge und Zusammensetzung der Sickerwasser*. Mitt. H. W. Inst. f. Landw. in Housberg, Band 3, 866-870-911. 1910.

278. *Losses of nitrogen and calcium.*—The most serious losses of plant nutrients in the drainage water of roads are those of nitrogen and calcium, and both are to an extent unavoidable. Potassium and phosphorus, which must also be purchased in manures, are lost only at the rate of a few pounds to the acre. Nitrogen and calcium may be conserved by maintaining a crop on the soil continually. A large removal of nitrogen in the drainage water is usually accompanied by a large removal of calcium; for nitrogen is leached from the soil mainly in the form of nitric acid, which of course reacts with a base, and calcium being the base finally liberated it is carried off in drainage water. While most of the calcium in drainage water is in the form of lime bicarbonate, the quantity is greatly increased by nitric acid.

The relation of nitric acid to calcium in drainage water is shown by experiments with soil in large-tanks from which drainage water was collected. Plants were grown in the soil of certain tanks, while others had none, other conditions being similar. Analyses of the drainage water at Ithaca, New York, as reported by Leonard Russell¹ show a greatly increased loss of calcium from the unplanted tanks, from which the loss of nitric nitrogen was also much greater:—

NEWCOMB AND CLARK'S RESULTS IN DRAINAGE TANKS AT ITHACA, N.Y., 1908, AND MAY 1, 1911. CALCULATED TO PERCENT OF THE LOSS.

| Case | Percent Nitrogen | Percent Calcium |
|-----------------|------------------|-----------------|
| None | 15.6 | 406.7 |
| Maize | 10.8 | 108.2 |
| Oats | 12.5 | 172.4 |

¹ *Irrig. '71*, and Russell, J. A. *Composition of the Drainage Water of a Soil with and without Vegetation*. Jour. Indus. and Eng. Chem., Vol. 3, pp. 762-763. 1911.

When crops were present to absorb the nitric acid, sodium was greatly concerned. The quantities of material carried off in drainage water was therefore abnormally high in this case, as the soil had recently been ploughed in the fields.

276. *Composition of surface water.*—Another method proposed for obtaining these data is to analyse and measure the water draining from a known area of land. Norton¹ has done this in the valley of Birkhead Creek, Arkansas, and has determined the loss of a number of the soil constituents. A comparison of the figures obtained by Norton with those obtained by Lyon and himself in the experiments just quoted will give some idea of the quantities of mineral matter removed from soils by drainage water. The Arkansas soil had presumably received little manure. The soil in the Cornell University fields had previously received fifteen tons of stable manure. The Arkansas drainage system included some surface water that had never passed through the soil and was therefore poor in mineral matter; the large quantity of soluble matter indicates its surface nature, as water that passes through a soil contains little organic matter.

There is little similarity in the results of these analyses. They serve, however, to bring out the difference between the composition of the run-off and the drainage water of soils, in as far as that may be judged from widely different soils and climatic conditions, including the rainfall.

¹Wheat, J. H. Quantity and Composition of Drainage Water and a Comparison of Temperature, Precipitation, and Evaporation. *Journal Am. Chem. Soc.*, Vol. 30, pp. 1190-1193, 1908.

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SEWELL'S RESULTS IN ILLINOIS WATER WITH GIVE ACID
OF LAKE. PRODUCE OF ONE YEAR

| | Pounds | Zinc use total | |
|-----------------------|--------|----------------|---------|
| | | Thousand | No. 100 |
| Total soil | 700.0 | 80 | 350 |
| Uppan water | 100.0 | 0 | 0 |
| Wetness | 4.0 | 11 | 11 |
| Depth | 5.0 | 5 | 10 |
| Thompson soil | 0.0 | Trace | Trace |
| Less | 80.0 | 100 | 400 |

It will be seen that the total solids in the drainage water from the Arkansas land and from the planted tank were not greatly different in amount, but that some of the constituents differed greatly. This was probably the case with organic matter and with lime. The former was doubtless carried largely in the run-off and not in the loadings. The latter was probably more abundant in the plastered soil used in the tank than in the natural soil of Arkansas.

CHAPTER XVII

ACID, OR MILD, SOILS

SOILS are known as acid, or mild, soils. The property of acidity is of practical significance because some plants do not grow so well on some soils as they do on soils that are acidified or alkalized; on the other hand, some crops prefer an acid soil. Some soils are nearly neutral with to acid regions, but in humid sections of the United States they are commonly found.

380. *Nature of soil acidity.*—Soils may be acid, we say, so far as their relation to plant growth is concerned, (1) when free acids are present, (2) when so soluble free acid exists, but when there is a deficiency of base material in the soil. Decomposition of organic matter in certain soils under an inadequate supply of oxygen often results in the formation of considerable quantities of organic acids, as has already been explained (p. 35).

381. *Positive acidity.* The formation of organic acids under conditions of insufficient oxygen supply is frequently seen in marsh and other soils high in organic matter that are saturated with water and that are also deficient in lime. In such cases an acid condition is very likely to be found, but when the land is drained the acidity usually disappears because of the better aeration resulting. Where a large quantity of green vegetation is plowed under, as is done in green-manuring land, a sour condition sometimes appears after the material has

had time partially to decay. The acidity of soil that arises from the presence of free acids has been termed *positive acidity*.

It is to be presumed that soils in which free acids exist are rather deficient in basic material, and that the bases are held so firmly combined that some of the relatively weak organic acid present is not capable of liberating salts with them. Plummer² has shown that dihydroxyacetic acid when added to an acid soil had a distinctly basic effect on wheat plants, but when added to the same soil previously treated with lime there was no basic effect, indicating that the substance restored its acid properties in the untreated soil.

282. Negative acidity. A soil deficient in basic material but containing no soluble free acids may be said to register its relation to plant growth. At least such a soil may be greatly benefited by liming, although it shows no acidity in most of the ordinary indications of acidity when these are used in the customary way. This condition has been termed *negative acidity* and is really not acidity according to a correct use of the word. Such acidity does not have a direct effect on the plant, but an indirect one arising from a lack of bases. Soils that are acid in this sense always have a large capacity for absorbing lime or other bases, before exhibiting so & before reaction. Calcium being so far already best seen (see 260), the baseness thereby reduced to neutrality, there is a tendency toward the formation of calcium carbonate in any soil dependent on the equilibrium be-

²Plummer, A. C. The behavior of Dihydroxyacetic Acid from Velvety Soil. Thesis presented in partial fulfillment of the requirements for the degree of Master of Science, Cornell University Library (not published). 1901.

toward the basic material and the absorptive substance in the soil. Thus, a soil containing large quantities of clay, and other absorbent substances requires more basic material for the formation of calcium carbonate than does a soil having low absorptive material. Furthermore, with the same original content of basic material, the former soil requires a greater addition of lime to overcome its acidity than that the latter. For this reason a heavy soil usually requires a larger dressing of lime to correct its acidity than does a light one.

Even if a soil does not have its absorptive capacity for lime satisfied, there is some formation of calcium carbonate constantly taking place, as is evidenced by the removal of the bicarbonate of calcium in the drainage water of soils that are distinctly acid. The bicarbonates that soils derive from the presence of calcium carbonate will be removed here (pp. 454-457). It need only be said here that its presence in insufficient quantity constitutes a form of so-called acidity, or sourness, in soils. The liberation of calcium carbonate in a given soil increases with the mass of lime. The effect of an application of lime, therefore, is to increase the quantity of carbonate formed, even when the absorptive capacity of the soil is not satisfied. This is why even relatively small applications of lime are beneficial to soils having great absorptive capacity.

35. Prevention of sour soils. — Soils in a humid region tend to become acid. This may be due to any one or more of several causes: (1) removal of calcium and other bases in drainage water; (2) removal of bases by plants; (3) liberation of acids of the bases with organic matter incorporated with soil; (4) accumulation of acid residues of fertilizers.

286. *Removal of bases by drainage as a cause for acidity.*—The most potent cause of acid soils is *drainage*, less the removal of bases in drainage water. The quantities of basic material that may be lost from an acre of soil are shown elsewhere (page 529, 535). These bases are removed largely or completely, being obtained from the hydrated aluminum silicates and other silicified matter. When the soil is irrigated a considerable loss of base occurs in the form of silicate. As the desiccation of the organic matter of the soil always results in the formation of carbon dioxide and nitric acid, and as desiccation is continually going on except when the temperature of the soil becomes too low to admit of it, the drain of bases from the soil is almost continuous. Formation of carbon dioxide and of nitric acid occurs largely in the surface soil; consequently the removal of bases begins there. The result is that soils are likely to contain less calcium in the surface layer than at lower depths. Ames and Gardner¹ have shown from a large number of analyses of Ohio soils that those containing calcium carbonate in appreciable quantities have more calcium in the subsoil than in the surface six inches. In other soils this was not uniformly the case. Lackling is, of course, greater in amount when considerable quantities of calcium carbonate are present than where it is lacking.

287. *Removal of bases by plants.*—Plants always remove more bases than acids from soils in the process of their growth. The table in paragraph 529 showing the composition of the soil of some crops indicates that the calcium, potassium, and magnesium removed from

¹ Ames, J. W., and Gardner, E. W. 8th Investigation Ohio Agr. Exp. Sta., Bul. 221, 1902.

the soil in this way is very considerable. When the vegetation on the land is returned to it after the crops and its organic material is again incorporated with the soil, there is no loss in this way, but in ordinary agricultural practice most of the above-ground portion of the crops is removed from the land. The nature of growing animals returns to the soil only a small proportion of the salphur that was originally in the plants.

Bonewell and LaTone¹ found that the selective action of plants in absorbing more bases than acids from a neutral solution caused the solution to become toxic to plant seedlings because of its acidity.

266. *Effect of green manures on acidity.*—Although the return of vegetation to the land on which it grew does not result in any actual loss of basic material to the soil, it generally results in the formation and liberation of organic acids that ridges with the basic material and thus render it neutral. In soils deficient in lime the incorporation of green-manure crops has been considered to temporarily produce an acid condition. Cooke² determined the acidity of some green-manure crops, on the basis of which he has suggested the acidity, in terms of ground limestone required to neutralize it, when the lime contained in the crop is deducted from the total lime required. This is given in the table on the next page.

¹ Bonewell, J. P., and LaTone, J. A. *The Growth of Wheat Seedlings as Affected by Acid or Alkaline Conditions*. U. S. D. A., Bur. Chem., Bul. 118, 1902.

² Cooke, J. V. *The Agricultural Utilization of Acid Soils by Means of Acid-Manured Crops*. U. S. D. A., Bul. No. 8, p. 5, 1903.

180 SOIL-PLANT PROPERTIES AND MANAGEMENT

WATER, TISSUE CONCENTRATIONS AND ANALYSES OF GRAIN MATERIALS
IN THE SOIL

| Cow | Water (liters) | 1931 Concentrations (percent) | Analysis of tissue in last year's crop (percent) |
|--------------|-------------------|-------------------------------------|---|
| Adams | 58 | 120 | 527 |
| Red clover | 7 | 181 | 562 |
| Chapman | 25 | 92 | 200 |
| Hay | 2 | 11 | 178 |
| Beaver ridge | 1 | 4 | 80 |

As decomposition proceeds the acids are oxidized, and finally basic material is left largely in combination with so-called bases of the soil. This is doubtless in the form of a colloidal complex, not a definite chemical compound. Analyses by Skyles¹ of purified humus soil from eight productive prairie soils have been averaged and are presented in tabular form in paragraph 97.

The quantity of basic material actually held by the organic matter of the soil is small compared with the total soil content. The bases contained in humus are principally potassium and sodium—not calcium, as might be expected in the soil of an organic acid formed in the soil. Humus in the soil tends to overcome acidity and functions as an alkali. In respect to its composition and properties, much of it resembles a colloidal complex rather than a chemical combination of soil bases with organic acids.

It has often been observed that land from which forest has been cleared will yield good crops of red clover for

¹ Skyles, Harry. 1916. *Minnesota Agr. Exp. Sta. Bul.* 41. 1916.

great degree, after which it becomes more and more difficult to obtain a crop and the attempt must finally be abandoned. The change from forest to tillage has opened the way for an acid condition of soil, through the loss of base cations of the crop and the destruction of humus by tillage. The dissipation of humus is doubtless the more serious source of loss. Farmers may be cited in which a field has been so managed as to maintain the humus supply and the ability of the soil to produce soil stores, although surrounding farms, on which humus has been depleted, have completely failed to grow the crop.

Apparently humus holds the basic constituents of the soil in a form in which they function as rather easily soluble salts, instead of locking them up as insoluble silicates. A given quantity of base in a soil is therefore more effective in preventing acidity by combining with weak acids, and possibly in forming esters, if the soil is well supplied with humus than if it is lacking in that constituent.

81. Effect of fertilizers on soil acidity.—That the continued use of ammonium sulfate on land may result in producing a more acid soil has been shown by a number of investigations. The absorption and utilization of the ammonia of that salt, and its final utilization by plants, leaves sulfate acid, which combines with calcium and nitrates in the drainage water. This may occur even when this fertilizer is used in quantities not excessive, but continued for many years, as has been shown by Guder and Brown¹ at the Paraguayan Experiment.

¹Guder, R. D., and Brown, R. E. The Nitrogen Requirement of the Grassland Pasture (Abstracts Periodically, *Agro. Paraguayan Agr. Exp. Sta.*, 1919-1921), pp. 22-24.

Salts. Other fertilizers having an acid residue in the soil also act in this way. It is reasonable that potassium chloride and potassium sulfate might have a tendency to produce an acid condition, but the bases in these salts do not disappear from the soil so quickly as would ammonia, and consequently their action is slower.

The use of lime sulfur on the land as a means of combating certain fungus diseases may lead to the formation of a more acid through the oxidation of the sulfur with formation of sulfuric acid. Hunt¹ has found that a soil in which sulfur was used at the rate of 100 pounds to the acre has production of potato roots changed in its lime requirement from 2431 pounds to 4177 pounds as a result of the one treatment.

298. Acidity in relation to climate and to formation of soil.—In an arid or a semiarid climate soils are not likely to become sour. The great source of lime removal, leaching, operates to only a slight extent, or not at all, in a dry climate. The removal of bases in crops is apparently offset by the upward movement of bicarbonates in the capillary water. Experience shows that acidity is not a problem in most of dry countries.

Soils that are derived from limestone or that have been mixed with limestone soils in the process of their formation are, under similar climatic conditions, less likely to become acid than any soils that originally contained lime free. The fact that a soil is derived from limestone, however, does not insure that it may not be benefited by an application of lime.

299. Fertilizers that furnish an acid salt.—The acidity or the basicity of salts influences very greatly the growth

¹ Hunt, H. Oxy. *The Influence of Sulfur on Soil Acidity*. Jour. Indus. and Eng. Chem., Vol. 6, pp. 707-748. 1914.

d vegetation and deterioration to a large degree in nature. The flora undergoes a considerable variation as a soil changes from a basic to a more acid condition. This is because some plants are injured to a greater extent than are others by the conditions that accompany an acid reaction of the soil. Some higher plants really grow better on a more acid than they do on an alkaline one, but these form only a minority of the plants of agricultural importance. Weeds that abound and appear to flourish on acid soils may be so either because they grow better on such soil than on basic, or because other vegetation growing on the soil does not thrive and therefore the dominant weeds of the region have less competition than they otherwise would have. There are certain weeds that may be taken to indicate a more acid when present in large numbers. Some of these are listed in one part of the country and none in another:—

| WEEDS OF PLACES ON SOILS BASE | |
|-------------------------------------|------------------------------|
| Common name | Botanical name |
| Sheep sorrel ¹ | <i>Rumex acetosella</i> |
| Pinktop ² | <i>Urtica urens</i> (common) |
| Daisy | <i>Bellis perennis</i> |
| Heavenly milk ³ | <i>Euphorbia corollata</i> |
| Corn spurry ⁴ | <i>Spergularia arvensis</i> |
| Wood horsetail ⁵ | <i>Equisetum sylvaticum</i> |
| Plantain ⁶ | <i>Plantago major</i> |
| Goose grass ⁷ | <i>Polygonum convolvulus</i> |

¹ Kirtley, A. L. *Acid Soils*. Oregon Agr. Exp. Sta., Ed. 10, p. 28, 1906.

² Wilson, A. B., and Vasey, W. W. *Soil Acidity and Liming*. Research Agr. Exp. Sta., Ed. 386, pp. 7-11, 1912.

³ Webster, J. A. *The Nature, Soil Experiment*. Trans. Royal Agr. Soc. England, Vol. 26, pp. 332-357, 1908.

200. *Crops adapted to sour soils.* There are some useful agricultural plants that grow better on sour soils than on alkaline soils, while other plants are apparently indifferent to the condition of the soil in this respect. As sour soils are of very common occurrence, and as the correction of this difficulty may not always be financially practicable or otherwise desirable, it is important to know what plants will thrive and how agricultural practice may be maintained on such soils. A list of these plants, based on different authorities, is herewith given:—

Crops American to New Ocean

| | |
|-------------------------------------|-----------------------------|
| Blueberry ¹ | Bairy vetch ¹ |
| Cranberry ¹ | Crimson clover ¹ |
| Strawberry ¹ | Potato ¹ |
| Blackberry ¹ | Sweet potato ¹ |
| Rasperry ¹ | Eye ¹ |
| Blackcap ¹ | Malva ¹ |
| Watermelon ¹ | Beetroot ¹ |
| Turnip ¹ | Cocoy ¹ |
| Red top ¹ | Lupine ¹ |
| Florida Island bogbean ¹ | Sorrel ¹ |
| Cowpea ¹ | Radish ² |
| Soybean ¹ | Velvet bean ¹ |

Cattle bean¹

The very considerable number of these plants, and especially the inclusion among them of legumes that may be grown for soil improvement, suggest the point

¹ Coville, D. W. *The Agricultural Utilization of Acid Land by Means of Acid-Tolerant Crops*. U. S. D. A., Bul. No. 6, pp. 7-22. 1911.

² Fitchner, R. A. *The Liming of Soils*. U. S. D. A., Bureau Bul. 77. 1906.

bility of a successful agricultural practice on acid soils, since the important worry crop to be grown, or some other condition, would make it inadvisable to correct the soil acidity. There are certain crops, such as blueberries and cranberries, that require an acid soil; there are others, such as potatoes, that may suffer less from acidity if the soil is sour. These crops are sometimes the ones that are of greatest financial importance in a region, and it therefore becomes desirable to maintain an acid condition of soil.

23. *Crops that are injured by acid soils.* There are many plants that are injured by a sour condition of the soil, and these include some of the most important farm crops. It should therefore be borne in mind that the most fertile produce on acid soil is very undesirable. One notable reason for this is that such crops as soil clover and alfalfa, which are of great value both as a means of improving soil and for hay, may be grown only with great uncertainty or not at all on acid soils.

CROPS INJURED AND LOST ON ACID SOILS¹

| | | |
|--------------------|---------------|-------------|
| Wheat | Sorghum | Cauliflower |
| Red clover | Squash | Cabbage |
| Silvage | Squash | Cucumber |
| Timothy | Red beet | Lettuce |
| Kentucky bluegrass | Soybeans | Onion |
| Maize | Butter | Peas |
| Oats | Sugar beet | Potatoes |
| Pepper | Cornmeal | Tomatoes |
| Peas | Mangel-wurzel | Turnips |
| Peas | Colony | Yucca |

¹ Whipple, B. J. The *Land of the U. S. A.*, 1908, p. 100.

While soils may be either sour or alkaline, there are also degrees of sourness. Thus a soil may be so sour as to completely prevent the growth of one kind of plant and yet produce excellent crops of another plant which would have perished if the soil had been more acid. For example, red clover will grow fairly well on soil that is too sour to raise alfalfa.

282. *Qualitative tests for acidity*.—A simple test to indicate an acid condition of soil is not so easy of execution as is often supposed. It is not so simple as to test for so infallible in its prediction as might be desired. The object of such a test is to ascertain whether a soil is acid and adapted to the growth of certain plants and whether the application of lime would benefit it in this respect. A number of tests have been proposed which will be outlined and briefly discussed.

283. *Litmus paper test*.—Blue litmus paper is brought into contact with the wet soil. A rapid and decided change to red is taken to indicate an acid condition of the soil. Cobaltine soil, which is always present in such, is supposed to give only a faint pink color to the litmus paper. Various ways of bringing the paper into contact with the soil have been recommended, among others the interposing of filter paper between the soil and the litmus paper.¹ It is also generally pointed out that the soil projection on the fingers may lead to indication.

A criticism of the test has been made by Cameron,² who states that the absorbent action of soils for lime is greater than that of paper, while for acids the reverse

¹ Kollerman, K. F., and Robinson, T. B. *Landscape Architecture and the Laboratory Detection of Acids*. U. S. D. A., Bur. Plant Indus., Cir. 75, pp. 2-5, 1905.

² Cameron, F. K. *The Soil Solution*, pp. 45-46. Dublin: Longmans, 1911.

is the case. Consequently the base that had produced the true color is absorbed from the bases, leaving the acid component, which is red. Clausen concludes that the test is unreliable, and proposes to titrate the soil with water, boil it in order to expel carbon dioxide, and then test the reaction of the solution.

Black filter paper that is sold is of very poor quality; but when good paper is used and the test is carefully made, the general experiences have been that it is a fairly good, although not an infallible, guide to the acid of a soil for time. Test coloration due to absorption action is probably an advantage rather than a source of error in the test, as a soil strongly absorbent of bases is likely to react fast. This coloration does not necessarily indicate the presence of free acid, but merely acid of time.

216. Ammonia test. In this test the soil is stirred with a dilute solution of ammonia hydroxide. After settling, if the supernatant liquid on standing takes on a dark coloration or a black color it is said to be acid. This method, which has been proposed by Allred,¹ is not of general application and would not always be reliable in the case of soils of acid regions. The depth of color is not a guide to the degree of acidity, since many acid soils are low in organic matter.

218. Zinc sulfide test. A test recently proposed by Trapp² consists in adding the soil to be tested with a small quantity of calcium chloride and a very little zinc sulfide. Water is added and the mixture is heated to

¹Wheeler, R. J., Howard, R. L., and Sargent, C. L. *Chemical Methods for Determining the Acid Requirements of Soils*. North Island Agr. Exp. Sta., Vol. 63, pp. 10-15, 1936.

²Trapp, R. A. *New Method for the Determination of Soil Acidity*. Science, 8, 8, Vol. 81, pp. 546-548, 1941.

boiling. A strip of moistened lead acetate paper is held over the mouth of the flask for two minutes while the boiling proceeds. If the soil is acid, the paper will be discolored on the underside; if the soil is not acid, no discoloring will occur.

This method is evidently designed to test the need of the soil for lime as well as actual acidity, for the absorption of calcium from the dissociated chloride would leave free hydrochloric acid. The action of this acid on the sulfide would generate hydrogen sulfide, thus blackening the lead acetate paper.

A somewhat similar principle is involved in the proposal to use a solution of potassium nitrate in the flame paper test.

283. *Lime paper and potassium nitrate.*—This is performed in the same manner as the former flame paper test, except for the substitution of a saturated solution of potassium nitrate instead of distilled water for moistening the soil.

297. *Acid test for carbonates.*—In this test a dry sample of the soil is treated with a few drops of dilute hydrochloric acid. Effervescence indicates the presence of carbonates or bicarbonates in sufficient quantities to insure an alkaline soil, although sometimes there may still be benefit.

Whitson and Weir¹ have objected to this method on the ground that the displacement of air in the pore spaces of the soil by the chloride acid may be mistaken for evolution of carbon dioxide. In the hands of an experienced and careful operator this would not necessarily invalidate the method.

¹Whitson, A. R., and Weir, W. W. *Soil Analysis and Liming*. Wisconsin Agr. Exp. Sta., Bul. 230, pp. 7-11, 1913.

29. *Plants as indicators of acidity.*—In addition to these chemical tests for acidity there may also be mentioned what is perhaps the most reliable indication of the need of lime, namely, the failure of a soil to produce red clover, and the presence of those weeds that have peculiarly been shown to thrive on sour soil (p. 205). When a soil bears this relation to the plant growth it may safely be assumed that those plants included in the list of crops that are injured by sour soils will yield better if the soil is limed than if it is not so treated. The correspondence to sour soils may not be injured.

30. *Quantitative determination of acidity.*—A number of quantitative methods for determining the degree of acidity or the lime requirements of soils have been devised. Only a few of these need be mentioned.

31. *Potassium nitrate method.*¹—The soil is shaken with a normal solution of potassium nitrate for three hours, and then allowed to stand overnight. An aliquot portion of the supernatant liquid is boiled in order to expel carbon dioxide, and when cool it is titrated with a standard solution of sodium hydroxide.

This method does not estimate either the free acid or the lime requirement of the soil. What it does is to give the alkaline power of the soil for potassium when in equilibrium with a solution containing the soil with which the potassium was originally in equilibrium. There is a substitution of bases during the contact of the nitrate solution with the soil, and a partial decomposition of these salts during the titration with alkali.

¹ Official and Provisional Methods of Analysis. Association of Official Agricultural Chemists. U. S. D. A., *Ann. Chem.*, Vol. XIV (periodic), p. 20, 1908.

391. *Desmoures' method*.—A measured quantity of a standard solution of Desmoures' is brought into contact with the soil and absorption is denoted off by centrifuge. On after which water is added and the filtrate is tested with phenolphthalein. When in presence a pink color shows that the lime requirement of the soil has not been reached; an alkaline reaction shows that an excess of lime has been added. A number of tests must be made in order to reach a point below which the indicator shows no color and above which it does. The lime requirement may thus be indicated. This determination was devised by Vetsch¹ and is a useful method since it indicates to within a few hundred pounds the quantity of lime required to satisfy the absorptive power of a soil.

392. *Reinard*.—In conclusion, a few facts regarding so-called acid soils may be related: (1) acidity is not always due to free acids, but often to the lack of an abundance of bases; (2) it is not injurious to all plants, but is likely to depress the yields of the majority of agriculturally important crops, while some valuable ones are benefited by it; (3) it may be overcome sometimes by action of the soil, and always by the application of lime or wood ashes. The correction of acidity by means of lime will be discussed in a later chapter, as will also the relation of certain bacteria to acidity.

¹ Vetsch, P. P. The Relationship of Soil Acidity and the Lime Requirements of Soils. Jour. Am. Chem. Soc., Vol. 24, pp. 1123-1126, 1902.

CHAPTER XVIII

ALKALI SOILS

It has already been shown that soils are acted upon by a great variety of weathering agents which gradually render soluble a portion of the most unyielding minerals. This soluble material becomes a part of the soil solution and may remain in contact with the roots of any crop growing on the soil. In humid regions, where a large quantity of water percolates through the soil, this soluble matter has little opportunity to collect. In arid regions, however, where loss by drainage is slight, these salts may often collect in large amounts. During periods of drought they are carried upward by the capillary rise of the soil water, while during periods of rainfall they may more downward again in proportion to the leaching action. At one time the lower soil may contain considerably more soluble salt than the upper; at another time the condition may be reversed, in which case the solution in contact with plant roots may contain so much soluble matter that vegetation is injured or destroyed. This action of soluble salts usually has a neutral alkaline reaction, but in some cases it produces what is termed an alkali soil.

III. Composition of alkali soils. — The materials dissolved in the soil water consist of all the substances found in the soil, but as the rates of solubility of these substances vary greatly there is accumulated a much larger quantity of some substances than of others. Carbonates, silicates,

and chlorides of sodium, potassium, calcium, and magnesium occur in the largest amounts. Sodium may be present as carbonate, sulfate, chloride, phosphate, and nitrate. Potassium may be similarly combined. Magnesium is likely to appear as a sulfate or a chloride, and calcium as a sulfate, a chloride, or a carbonate. The salt will predominate in some soils, and other salts in other soils. A base may be present in combination with several different salts. The nature of the prevailing salt greatly influences the effect on vegetation. The table on page 201 gives the composition of the soluble salts from a number of alkali soils.

A few years ago Woodcock¹ called attention to large accumulations of nitrates in certain localities in California. These salts dissolve in the soil water and are frequently present in such large quantities as to be injurious to vegetation.

336. White and black alkali.—Sulfates and chlorides of the alkalies, when concentrated on the surface of the soil, produce a white incrustation, which is very common in alkali regions during a dry period as a result of evaporation of moisture. Incrustations of this character are called white alkali.

Carbonates of the alkalies, particularly sodium carbonate, dissolve organic matter from the soil, thus giving a dark color to the solution and to the incrustation. The thick masses of soil containing large quantities of these salts is called black alkali. Black or brown alkali may also be produced by calcium chloride or by an excess of sodium nitrate.

¹ Henshaw, V. P. Determination in the Quality of Sugar Beets Due to Nitrates Found in the Soil. *Citizens' Rep.* No. 86, Vol. 186. 1904.

THEORETICAL COMPOSITION OF ANALYTICAL REAGENTS

| Compound | Formula | Weight of compound in 100 g. of reagent | Weight of element in 100 g. of reagent | Percentage of element in reagent |
|--|--|---|--|----------------------------------|
| Al | Al | 100.00 | 100.00 | 100.00 |
| Al ₂ O ₃ | Al ₂ O ₃ | 101.96 | 101.96 | 100.00 |
| Al(OH) ₃ | Al(OH) ₃ | 78.00 | 78.00 | 100.00 |
| Al ₂ (SO ₄) ₃ | Al ₂ (SO ₄) ₃ | 342.15 | 342.15 | 100.00 |
| Al ₂ (CO ₃) ₃ | Al ₂ (CO ₃) ₃ | 300.00 | 300.00 | 100.00 |
| Al ₂ (C ₂ O ₄) ₃ | Al ₂ (C ₂ O ₄) ₃ | 324.00 | 324.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ | Al ₂ (C ₂ H ₃ O ₄) ₃ | 342.15 | 342.15 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 3H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 3H ₂ O | 408.00 | 408.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 9H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 9H ₂ O | 540.00 | 540.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 18H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 18H ₂ O | 672.00 | 672.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 27H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 27H ₂ O | 804.00 | 804.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 36H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 36H ₂ O | 936.00 | 936.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 45H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 45H ₂ O | 1068.00 | 1068.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 54H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 54H ₂ O | 1200.00 | 1200.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 63H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 63H ₂ O | 1332.00 | 1332.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 72H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 72H ₂ O | 1464.00 | 1464.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 81H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 81H ₂ O | 1596.00 | 1596.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 90H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 90H ₂ O | 1728.00 | 1728.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 99H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 99H ₂ O | 1860.00 | 1860.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 108H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 108H ₂ O | 1992.00 | 1992.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 117H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 117H ₂ O | 2124.00 | 2124.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 126H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 126H ₂ O | 2256.00 | 2256.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 135H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 135H ₂ O | 2388.00 | 2388.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 144H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 144H ₂ O | 2520.00 | 2520.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 153H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 153H ₂ O | 2652.00 | 2652.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 162H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 162H ₂ O | 2784.00 | 2784.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 171H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 171H ₂ O | 2916.00 | 2916.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 180H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 180H ₂ O | 3048.00 | 3048.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 189H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 189H ₂ O | 3180.00 | 3180.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 198H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 198H ₂ O | 3312.00 | 3312.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 207H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 207H ₂ O | 3444.00 | 3444.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 216H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 216H ₂ O | 3576.00 | 3576.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 225H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 225H ₂ O | 3708.00 | 3708.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 234H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 234H ₂ O | 3840.00 | 3840.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 243H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 243H ₂ O | 3972.00 | 3972.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 252H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 252H ₂ O | 4104.00 | 4104.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 261H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 261H ₂ O | 4236.00 | 4236.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 270H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 270H ₂ O | 4368.00 | 4368.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 279H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 279H ₂ O | 4500.00 | 4500.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 288H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 288H ₂ O | 4632.00 | 4632.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 297H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 297H ₂ O | 4764.00 | 4764.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 306H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 306H ₂ O | 4896.00 | 4896.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 315H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 315H ₂ O | 5028.00 | 5028.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 324H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 324H ₂ O | 5160.00 | 5160.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 333H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 333H ₂ O | 5292.00 | 5292.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 342H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 342H ₂ O | 5424.00 | 5424.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 351H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 351H ₂ O | 5556.00 | 5556.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 360H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 360H ₂ O | 5688.00 | 5688.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 369H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 369H ₂ O | 5820.00 | 5820.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 378H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 378H ₂ O | 5952.00 | 5952.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 387H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 387H ₂ O | 6084.00 | 6084.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 396H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 396H ₂ O | 6216.00 | 6216.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 405H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 405H ₂ O | 6348.00 | 6348.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 414H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 414H ₂ O | 6480.00 | 6480.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 423H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 423H ₂ O | 6612.00 | 6612.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 432H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 432H ₂ O | 6744.00 | 6744.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 441H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 441H ₂ O | 6876.00 | 6876.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 450H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 450H ₂ O | 7008.00 | 7008.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 459H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 459H ₂ O | 7140.00 | 7140.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 468H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 468H ₂ O | 7272.00 | 7272.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 477H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 477H ₂ O | 7404.00 | 7404.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 486H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 486H ₂ O | 7536.00 | 7536.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 495H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 495H ₂ O | 7668.00 | 7668.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 504H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 504H ₂ O | 7800.00 | 7800.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 513H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 513H ₂ O | 7932.00 | 7932.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 522H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 522H ₂ O | 8064.00 | 8064.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 531H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 531H ₂ O | 8196.00 | 8196.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 540H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 540H ₂ O | 8328.00 | 8328.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 549H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 549H ₂ O | 8460.00 | 8460.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 558H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 558H ₂ O | 8592.00 | 8592.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 567H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 567H ₂ O | 8724.00 | 8724.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 576H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 576H ₂ O | 8856.00 | 8856.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 585H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 585H ₂ O | 8988.00 | 8988.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 594H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 594H ₂ O | 9120.00 | 9120.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 603H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 603H ₂ O | 9252.00 | 9252.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 612H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 612H ₂ O | 9384.00 | 9384.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 621H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 621H ₂ O | 9516.00 | 9516.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 630H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 630H ₂ O | 9648.00 | 9648.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 639H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 639H ₂ O | 9780.00 | 9780.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 648H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 648H ₂ O | 9912.00 | 9912.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 657H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 657H ₂ O | 10044.00 | 10044.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 666H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 666H ₂ O | 10176.00 | 10176.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 675H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 675H ₂ O | 10308.00 | 10308.00 | 100.00 |
| Al ₂ (C ₂ H ₃ O ₄) ₃ · 684H ₂ O | Al ₂ (C ₂ H ₃ O ₄) ₃ · 684 | | | |

Black alkali is much more destructive to vegetation than is white. A quantity of white alkali that would not seriously interfere with the growth of most crops might completely prevent the development of such plants if the alkali were black.

35. *Effect of alkali on crops.*—The presence of relatively large amounts of salts dissolved in water and brought into contact with a plant cell has been shown to cause a shrinkage of the protoplasmic lining of the cell, the shrinkage increasing with the concentration of the solution. This causes the plant to wilt, to grow poorly, and finally to die. The nature of the soil, and the species and even the individuality of the plant, determine the point of concentration at which the plant succumbs.

The directly injurious effect of the chlorides, sulfates, nitrates, and other salts of the alkalies and alkali earths is due to this action on the cell contents of the plants. The mechanism of the situation here, in addition, a connecting effect on the plant tissues, dissolving the part of the plant with which they come in contact. Indirectly alkali salts may injure plants by their influence on the soil flora, soil organisms, and fungus and bacterial diseases.

36. *Effect on different plants.*—The factors that determine the tolerance of plants toward alkali are: (1) the physiological constitution of the plant; (2) the rooting habit. The first is not well understood, but resistance varies with species, and even with individuals of the same species. So far as the rooting habit, resistance to alkali, the advantage is with the deep-rooted plants such as alfalfa and sugar beets, probably because a part of the root is in a less strongly impregnated part of the soil.

(Of the seeds, barley and oats are the most tolerant, those being able in some cases to produce good crops and containing two-thirds per cent of vitric acid). Of the longer crops, a number of valuable grasses are able to grow to soil containing considerably more than two-thirds per cent of alkali. Timothy, meadow fescue, and alfalfa are the cultivated forage plants most tolerant of alkali, although they do not equal the native grasses in this respect. Cattle also tolerate a considerable amount of alkali.

Loughridge¹ after experiments and observations for a number of years, has tabulated data regarding the resistance of various crops to the several alkali soils. His results are given in part below, expressed in pounds to an acre to a depth of four feet:—

| Crop | Salt | Water | Acid | Total Value |
|---------|--------|-------|------|-------------|
| Oats | 40,000 | 2,200 | 0.20 | 8,700 |
| Barley | 30,000 | 2,800 | 0.20 | 21,000 |
| Wheat | 27,000 | 1,700 | 0.20 | 10,000 |
| Alfalfa | 16,500 | 800 | 0.20 | 11,000 |
| Timothy | 9,000 | 900 | 0.20 | 11,000 |
| Hay | 9,000 | 900 | 0.20 | 11,000 |
| Wheat | 12,000 | 1,100 | 0.20 | 13,000 |
| Barley | 12,000 | 1,100 | 0.20 | 13,000 |
| Wheat | 12,000 | 1,100 | 0.20 | 13,000 |
| Alfalfa | 12,000 | 1,100 | 0.20 | 13,000 |
| Timothy | 12,000 | 1,100 | 0.20 | 13,000 |
| Hay | 12,000 | 1,100 | 0.20 | 13,000 |

¹Loughridge, H. H. *Production of Alfalfa by Various Crops*. California Agr. Exp. Sta., Vol. 121, 1901. See also Murray, T. H., and Loughridge, H. H. *Comparative Values of Various Plants for the Alkali Soils of the United States*. U. S. D. A., New Plant Series, Vol. 112, 1907.

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Although in general the results as to the resistance to alkali of the various crops are so conflicting, the Bureau of Soils¹ in its alkali mapping, has been able to make a rough classification as follows:—

| Percentage of Total Area | Percentage of Total Area | Crops |
|--------------------------|--------------------------|--|
| 0 to 0.20 | Less than 0.05 | All crops grow |
| 0.20 to 0.40 | 0.05 to 0.10 | All but most sensitive |
| 0.40 to 0.60 | 0.10 to 0.20 | Old alfalfa, sugar beet, barley, and cereals |
| 0.60 to 1.00 | 0.20 to 0.40 | Only most resistant plants |
| 1.00 to 2.00 | 0.40 and above | No plants |

331. Other conditions that influence the action of alkali.—The higher the water content of the soil, the less is the injury to plants from alkali; but should the water still be more dry, the previous large quantity of water tends, by bringing this solution a large amount of alkali, render the solution stronger than it would otherwise have been, and thus cause greater injury (see Fig. 55).

The distribution of the alkali at different depths may have an important bearing on its effect on plants. Young plants and shallow-rooted crops may be entirely destroyed by the concentration of alkali at the surface, while the same quantity evenly distributed through the soil, or carried by moisture to a lower depth, would have caused no injury. A heavy soil, by reason of its greater water-holding capacity and absorptive power, will exert more alkali without injury to plants than will a sand

¹ Dwyer, C. W. Alkali Soils of the United States. U. S. D. A., Bur. Soils, Bul. 26, pp. 22-25, 1904.

after irrigation has been practiced for a few years. This is due to what is known as a "rise of alkali," and comes about through the accumulation, near the surface of the soil, of salts that were formerly distributed throughout a depth of perhaps many feet. Before the land was irrigated, the rainfall penetrated only a slight depth into the soil, and when evaporation took place, salts were drawn to the surface from only a small volume of soil. When, however, irrigation water is turned on the land, the soil becomes wet to a depth of perhaps fifteen or twenty feet. During this portion of the year in which the soil is allowed to dry, large quantities of salts are carried toward the surface by the upward-moving capillary water. Although these salts are in part carried down again by the next irrigation, the upward movement certainly exceeds the downward run. This is because the descending water passes largely through the non-capillary interstitial spaces, while the ascending water passes entirely through the capillary spaces. The smaller spaces, therefore, contain a considerable quantity of soluble salts after the downward movement ceases and the upward movement begins. In other words, the volume of water carrying the salts downward in the capillary spaces is less than that carrying them upward through these spaces. Surface tension causes the salts to accumulate largely in the capillary spaces, and it is therefore the direction of the principal movement through these spaces that determines the point of accumulation of the alkali.

There are large areas of land in Egypt, in India, and even in France and Italy, as well as in this country, that have suffered in this way, and not infrequently they have resorted to a direct alkali.

310. The handling of alkali lands¹—(thoroughly there are two general ways in which alkali lands may be handled in order to avoid the injurious effect of soluble salts. The first of these is rendering the spongy soil to be irrigated as control. In the former case, an attempt is made to actually eliminate by various means some of the alkali. In the latter, methods of soil management are employed which will keep the salts well distributed throughout the soil. In many cases this would grow excellent crops if the alkali could only be kept well distributed through the soil layers so that no toxic action could come at least within the root zone. In general, steps should always be taken toward the control of alkali, whether eradication is attempted or not. Under irrigation, control method is always wise.

311. Reclamation of alkali.—(2) methods designed to at least partially free the soil of alkali, the commonest are: (1) leaching with underdrainage, (2) correction with gypsum, (3) cropping, and (4) liming.

312. Leaching with underdrainage.—Of the various methods for removing an excess of soluble salts, the use of 44 drains is the most thorough and satisfactory. When this method is used in an irrigated region, heavy and repeated applications of water must be made to flush out the alkali from the soil and drain it off through the tile. When used for the reclamation of alkali spots

¹ Thomas, C. W. Reclamation of Alkali Soils. U. S. D. A., Agr. Res. Bul. 34, 1921. Also, Elwood, J. W. Drainage and Reclamation of Alkali Lands, Salt. New York, 1911. Also, Brown, C. P., and Frost, W. L. Reclamation of Spongy and Alkali Lands. Utah Agr. Exp. Sta., Bul. 113, 1909. Also, Conroy, C. T. Reclamation of Alkali Soils at Billings, Montana. U. S. D. A., Agr. Res. Bul. 46, 1922.

in a percolated region, the natural rainfall will in time effect the removal.

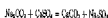
In laying tiles it is necessary to have them at such a depth that soluble salts in the soil beneath them will not readily rise to the surface. This will depend on the properties of the soil governing the capillary movement of water. Three or four feet in depth is usually sufficient, but the capillary movement should first be estimated.

After the drains have been placed, the land is flooded with water to a depth of several inches. The water is allowed to soak into the soil and to pass off through the drains, leaching out part of the salts in the process. Before the soil has time to become very dry the flooding is repeated, and the operation is kept up until the land is brought into a satisfactory condition.

Crops that will stand flooding may be grown during this treatment, and they will serve to keep the soil from puddling, as it is likely to do if allowed to become dry on the surface. If crops are not grown, the soil should be harrowed between floodings. The operation should not be carried to a point where the soluble salts are reduced below the needs of the crop, or so low that they lose entirely their effect on the retention of moisture.

232. Correction with gypsum.—The use of gypsum on black shal¹ land has sometimes been practiced for the purpose of converting the soluble carbonates into sulphates, thus neutralizing the injurious properties of the shal¹ without decreasing the amount. The quantity of gypsum required may be calculated from the amount and composition of the shal¹. The soil must be kept moist, in order to bring about the reaction, and the

growth should be lowered into the surface, not plowed under. The reaction is as follows:—



When soil containing black alkali is to be desalinated, it is recommended that the land shall first be treated with gypsum, as the substitution of alkali sulfates for carbonates causes the soil to assume a much less compact condition and thus facilitates drainage. It also prevents the loss of organic matter dissolved by the carbonates of soda and the soluble phosphates, both of which are precipitated by the change.

214. Seepage. Removal of the alkali incrustation that has accumulated at the surface is sometimes essential. Very often the rise of alkali is encouraged by applications of irrigation water, which is allowed to evaporate uncontrolled. The salts are thus carried upward by the capillary movement of the soil water. The method of alkali eradication is never very efficient, and is often dangerous, as it encourages the presence of very large amounts of alkali salts in the surface soil.

215. Flooding.—Often alkali accumulations may be washed from the soil surface by turning on a rapidly moving stream of water. The texture of the soil, as well as the slope of the land, must be just right for such a procedure. Generally so much water enters the soil that the land remains heavily impregnated with alkali salts. Both this method and the previous one, even if successful, are only temporary. Moreover, both require so much alkali as to admit of either one of these procedures may be so heavily charged as never to yield to any form of other eradication or control.

314. *Control of alkali*.—Where excessive amounts of soluble salts do not exist in a soil, the control of the alkali with a view of keeping it well distributed in the soil column is the best practice. The introduction of gypsum is, of course, the main object in this procedure. The intensive use of the soil water is therefore to be advocated, especially in all irrigation operations where alkali concentrations are likely to occur. Such a method of soil management not only saves accidents, but also prevents the excessive translocation of soluble salts into the soil zone. This method of control is the most economical, the cheapest, and the one to be advocated on all occasions, no matter what may have been the previous source of dealing with the alkali situation.

315. *Cropping with tolerant plants*.—Certain soils that are strongly impregnated with alkali may be gradually improved by cropping with sugar beets and other crops that are tolerant of alkali and that remove large quantities of salts. This is more likely to be effective where irrigation is not practised. Certain crops, moreover, while somewhat seriously injured while young, are very resistant once their root systems are developed. A good example is alfalfa, the young plants being very tender while the more mature ones are extremely resistant. The heavy application of alkali may allow such a crop to be established. It will then maintain itself in spite of the concentrations that may later occur.

316. *Alkali soils*.—In some cases small areas of alkali are often found, varying from a few square yards to several acres in size. The quantities of alkali in them are usually not sufficient to prevent the growth of plants in years of good rainfall, but in periods of drought the concentration of the salts and the compact condition that

(big text) to produce suitable to types the crop. The methods already mentioned for treating wheat land use of service to these small areas, and, in addition, the possibility of fresh farm resource has been found to improve their productivity. This, with various drainage, deep ploughing, and good cultivation is only to prevent the soil from drying out, will usually remedy the difficulty. In many cases these spots become highly productive under proper treatment.

CHAPTER XIX

ABSORPTION OF NUTRITIVE SALTS BY AGRICULTURAL PLANTS

As the salts taken up by the roots of agricultural plants are in solution when absorbed, the movement into the root thus depends on the presence of moisture, which is the medium of transfer. The root-hairs are the great absorbing organs of the plant, and through the cells of their delicate tissues the solution of the various salts are passed.

115. *How plants absorb nutrients.*—The nature and quantity of material absorbed by a plant is determined by the law of diffusion. From the cells of the root-hairs the dissolved salts are transferred to other parts of the plant, where they undergo the metabolic processes that determine which constituents shall be retained in the tissues of the plant. The unused ions that remain in the plant juices prevent by their presence the further absorption of those particular substances from the soil water. It thus happens that the composition of the ash of a plant may be very different from that of the substances present in it in solution. For example, nitrogen, although always present in the soil in a very slightly soluble form, is present in more than in the ash of most plants. On the other hand, iodine, although present in sea water only in the most minute quantities, is present in large quantities in the ash of certain marine algae.

A plant will, in general, take up more of a nutritive substance if it is presented in large amount, as compared with the other while substances in the nutrient solution, than if it is presented in small amount. Thus, the percentage of nitrogen in maize, oats, and wheat may be increased by increasing the ratio of nitrogen to other nutritive substances in the nutrient media. This is also true of potassium and phosphorus, respectively. The fact is accounted for by the maintenance of the relative equilibrium at a higher level for a particular ion which is relatively abundant in the nutrient solution, thus preventing the return of the excess from the plant.

103. *Relation between root-hairs and soil particles.*—In a rich, moist soil the number of root-hairs is very good, while in a poor or a very dry soil or in a saturated soil there are comparatively few root-hairs. The connection between the root-hairs and the soil particles is extremely intimate. When in contact with a particle of soil, a root-hair in many cases almost fuses it, and by means of its mucilaginous wall forms a mallet so close to practically to make the solution between the portion of the soil wall detached from that between the soil particles themselves.*

There has been considerable difference of opinion as to how a plant can obtain its mineral nutrients from a substance so difficultly soluble as the soil. This has arisen because of the conflicting nature and the inadequate character of the data available.

104. *Living and Sachs on nutrient action of plant roots.*—Lodge[†] called attention to the fact that a plant may obtain one hundred times as much phosphorus and

* *See* e.g., J. The Chemist in New Association of Agricultural, 1902.

nitrogen and fifty times as much potassium as can be extracted from the same volume of soil with pure water or with water containing carbon dioxide. It has, of course, been recognized that the soil water is itself in a solvent action by a variety of substances that may be normally present in solution, beginning with the gases taken up by roots in its descent through the atmosphere, and further added to by the carbon dioxide and the organic and mineral substances obtained from the soil. It has been held that the plant roots act as solvents of mineral matter by excretion of acids, which act effectively as solvents. The well-known root tracings on limestone and marble have been taken as proof of the excretion of rock acids. Sachs,¹ and later other investigators, grew plants of various kinds in soil and other media in which was placed a slab of polished marble or dolomite or calcium phosphate, covered with a layer of washed sand. After the plants had made sufficient growth the slabs were removed, and on the surfaces were found circular markings, corresponding to the lines of contact between the roots and the minerals.

422. Chapin's experiments.—In order to test this theory, Chapin² repeated the experiments of Sachs, using plates of gypsum mixed with the ground mineral that he wished to test, and this mixture he spread over a glass plate. Using these plates in the same manner as previously described, Chapin found that, while plates of calcium carbonate and of calcium phosphate were corroded by the plant roots, plates of aluminum phosphate

¹ Sachs, J. *Lehrbuch des Mineralnährs*. *Mineral-Nährstoffe*. Bot. Jahrbuch, *Reihe* 2:17-119. 1903.

² Chapin, F. *For Letters see 656 Wissenschaftliche Zeitsch. f. Wis. Berl.*, Band 10, Seite 253-256. 1896.

point out. He concludes that if the findings are due to acids excreted by the plant roots, the acids so excreted must be those that have no solvent action on aluminum phosphate. This would limit the excreted acids to malic, succinic, propionic, and butyric. Campbell also replies to the argument that the acids producing the findings must be non-volatile ones because of the definite flow made in the material, by stating that the excretion of carbon dioxide alone would be sufficient to account for the observations since it dissolves in water to form one-fourth carbonic acid, and that carbonic acid is always present in the soil water of the root system. By means of microchemical analyses of the excretions of root-tips grown in a super-saturated atmosphere, Campbell found potassium, magnesium, calcium, phosphorus, and chlorine in the excretions. He concludes that the solvent action of plant roots is due to acid salts of mineral acids, particularly acid potassium phosphates. He has not proved, however, that the excretions were not from dead root hairs nor from the dead cells of the rhizome. In either case they would have some solvent action, but whether sufficient to make them of importance is doubtful.

555. *Secretion of an oxidizing enzyme by plant roots.*—Marsch¹ found that endolites secrete a substance having properties corresponding to those of an oxidizing enzyme. His work has been repeated by others who have failed to obtain similar results, but lately Schinner and Dine² have

¹Marsch, R. *Über Wurzelendoliten und deren Bedeutung für Symphektin-Rhizomycen*, *Monat. Bot. Wiss.-Med.*, 1914, Band 46, Seite 161-166, 1915. Also *Ann. d. Chem. Gesells.*, Band 48, Seite 1513, 1916, and in *Geogr. F. Agr. Chem.*, Band 17, Seite 125, 1916.

²Schinner, Oswald, and Dine, F. S. *Beitrag zu den Oxidations-Enzymen der pflanzl. Welt*, *Chem. Zentr.*, 1916, p. 161.

demonstrated an oxidizing action of roots that is apparently due to a peroxidase. Oxidation alone, however, would hardly suffice to account for the solvent action accompanying the development of plant roots, although it is doubtless an important function and useful to other ways.

5th. Importance of carbon dioxide as a solvent.—Stollman and Ernst¹ have contributed much to this subject during the last decade. Stollman's earlier experiments, conducted by maintaining the plant roots in a saturated atmosphere, gave only carbon dioxide in the analysis. In this he is in agreement with most of the recent investigations of this subject. Stollman emphasizes the importance of carbon dioxide as a solvent by showing the quantity produced by plants and by microorganisms. He estimates that in one acre of soil to a depth of sixteen inches there are sixty-eight pounds of carbon dioxide produced by bacterial respiration in two hundred days, and fifty-four pounds of carbon dioxide excreted by plant roots in one hundred days; these periods he considers as representing the year's activity of bacteria and higher plants.

In later experiments, Stollman and Ernst² found that when plants do not have a sufficient supply of oxygen in the air surrounding their roots, they secrete acids and hence acids form the root-lanes. These investigations believe that these acids are toxic rather than beneficial.

¹ Stollman, J., and Ernst, A. Ueber den Ursprung des Sauerstoffs und die Bedeutung des Kohlendioxids im Boden. *Centralblatt. D. Landw. u. Forst.* 1910-1911. 1912.

² Stollman, J., and Ernst, A. Beiträge zur Lösung der Frage des Sauerstoffbedarfes des Wurzelorgans. *Zeitsch. f. Wiss. Bot.*, Band 47, Heft 32-33. 1910-1911.

and that they are responsible, in large measure, for the injurious effect on plants of a very compact condition of soil. In the same communication these authors report an experiment in which it was found that the kinds of plants that secure the largest quantity of carbon dioxide from their roots are the ones that absorb the greatest quantities of phosphorus from quinine and from bicarb. This, however, does not necessarily connect any causal relation between these physiological functions. Bunsen¹ drew air through plants with constant in large tubes. He found that the maximum production of carbon dioxide occurred at the time when the plants were blossoming, whether the plants blossomed early or late in the season. This he considered to indicate that the plant acquires most vigorously in the selection of nutritive materials at the time when it is most active in absorbing them.

124. Inefficiency of carbon dioxide.—Miller and Black² passed carbon dioxide through soil contained in vessels in which plants were growing. The soil in some vessels contained a difficulty soluble trisodic phosphate; that in other vessels the more easily soluble double phosphate, and that in still other vessels was unfertilized. Another set of vessels having the same fertilizer treatment received no carbon dioxide. The soil receiving carbon dioxide produced larger yields of dry matter and phosphorus in

¹Bunsen, F. The Carbon Dioxide Content of Soil at Different Periods of Plant Growth. Jour. Roy. Agr. Soc. (London), Vol. 11, pp. 522-542, 1880. The authors are indebted to Dr. J. Thurston for a translation of this paper.

²Miller, W., and Black, E. Die Düngemittelwirkung bei Versuchs und der Einwirkung des Kohlendioxids in Kohlenstoffdüngung. Pflanzen. Landw. Vers. Stat., Band 17, Seite 107-109, 1911.

the crop on the soil to which diatomic phosphate had been applied than did the soil not receiving carbon dioxide; but the soil to which no phosphate was added yielded equally well whether it received carbon dioxide or not. The plants used were oats, peas, and lupines. These investigators conclude that carbon dioxide is not a sufficient solvent to account for the mineral nutrients obtained from soils by plants.

286. The present status of the question. The soil also conducts an excretion of acids other than carbonic by the roots of plants does not admit of any very satisfactory conclusion as to their relative importance in the acquisition of plant-food materials. There can be no doubt, however, that carbon dioxide resulting from soil exhalation and from decomposition of organic matter in the soil plays a very prominent part in this operation. The very large quantity of carbon dioxide in the soil, amounting in some cases to from 10 to nearly 50 per cent of the soil air, or several hundred times that of the atmospheric air, must aid greatly in dissolving the soil particles.

Whatever may be the concentration of the soil water, it seems probable that the liquid which is forced when the root-hair comes in contact with the soil particles, and which is separated, in part at least, from the percolates of the soil water, must have a density much greater than that found elsewhere in the soil. That portion of the soil water immediately in contact with the soil particle is a much stronger solution than the water farther from the soil surface, because of the absorptive action of the particles.

Many plants grow in solutions of nutritive salts, less free of carbonic acids, but absorb through the epidermal

case of the roots. If the plant depended wholly on the prepared solution in the soil water, a similar structure would doubtless suffice. The special modification by which the root-hairs come in intimate contact with the soil particles and absorb material, indicates a direct relation between the soil particles and the plant, and not merely between the soil solution and the plant.

New root-hairs are constantly being formed, and the old ones become inactive and disappear. The contact of a root-hair with a soil particle is not permanent. Whether the period of contact is determined by the ability of the root to absorb nutriment from the particle is not known. Certain it is that only a small portion of the particle is removed.

337. Possible root action on colloidal complexes.—It has already been stated that there is some evidence to lead to the belief that the surfaces of soil particles are covered to a large extent with colloidal complexes, composed of both organic and inorganic matter having viscous adhesive properties and holding the bases and phosphates in an absorbed condition. Roots of growing plants have been found to cause coagulation of at least some colloids, possibly by leaving an acid residue in the solution solution by reason of the selective absorption of bases and rejection of the acids of the dissolved salts. It is conceivable that the root-hair, by removing bases from the solution coming between the soil wall and the colloidal covering of the soil particle, may cause coagulation of the colloidal matter and thus liberate the plant-food materials held by absorption. The liberated material, being still readily soluble nature, would be taken up by the extension between the rootlet and the soil particle, from which the root-hair could readily absorb it. Such

an hypothesis would account for the ability of plants to obtain a quantity of nutrient materials far in excess of what can be accounted for by the solvent action of pure water, and even hoped what heavy investigations are willing to attribute to the solvent action of water charged with carbon dioxide.

324. *Why crops vary in their absorptive power.*—As has already been pointed out (p. 321-322), crops of different kinds vary greatly in their ability to draw nutriment from the soil. The difference between the nitrogen, phosphorus, and potassium taken up by a corn crop of average size and a wheat crop of average size is very striking. In the table on page 310 it is seen that two tons of red clover contain three times as much potash, nearly ten times as much lime, and somewhat more than three times as much phosphorus as a crop of thirty bushels of wheat including the straw.

The difference in absorbing power may be due to either one or both of two causes: (1) a larger absorbing system; (2) a more active absorbing system. The former is determined by the extent of the root-hair surface; the latter by the intensity of the absorbing action.

325. *Form of absorbing system.*—Plants with long root systems may be expected to absorb the larger amount of nutriment from the soil. Such is usually the case, although the extent of the root system is not necessarily proportional to the total area of the absorbing surface of the root hairs.

326. *Absorptive Activity.*—The absorptive activity of a plant under any given condition of soil and climate depends on: (1) the rapidity and completeness with which the plant abstracts the substances taken from the soil into plant solution, or otherwise removes them from

solution; (2) the extent to which the substances from the medium—whether these be carbon dioxide, salts of mineral acids, or organic acids—are on the soil particles. The first of these is a function of the vital energy of the plant and its ability to utilize minerals and carbon dioxide to produce organic matter. It may be compared to the property which enables one animal to do more work than another animal of the same weight on a similar ration.

The pressure from the ascending water current in the plant of substances derived from the soil is unopposed in the leaves. By the dissipation of these substances, nutrients are thereby furnished for metabolism into materials that may be built into the tissues of the plant. The resistance force set kept in the solution. There is a constant tendency to bring the composition and density of the solution into equilibrium, by diffusion and osmosis, with the solution between the soil particle and the root-hair. The rapidity with which the metabolic process removes a substance from the solution in the plant, therefore, determines the rate at which it is removed from a solution of given composition and density in the soil. Plants making a rapid growth remove more nutrients in a given time than those making a slower growth, when the nutrient solution is of a given composition and density.

Another factor that affects the rate of absorption of salts from the soil is the solvent influence of exudates from the root-hairs. This subject has already been considered (p. 35-136), and it only remains to be said that this action obviously varies with different kinds of plants, and probably amounts to no small measure for the difference in the ability of different plants to withdraw salts from the soil.

These several factors, which, when considered, deter-

vise the so-called "feeding power" of the plant, as recognized by the popular terms "weak feeder" and "strong feeder,"—applied, on the one hand, to such crops as wheat or oats, which require very careful soil preparation and manuring, and, on the other hand, to such crops as corn, or cabbage, which demand relatively less care. In the manuring and sowing of crops, this difference in absorptive power must be considered, in order not only to secure the maximum effect on the crop intended, but also to get the greatest residual effect of the manure on succeeding crops.

381. The absorptive power of cereals.—Cereals have the power of utilizing the phosphate and phosphorus of the soil to a considerable degree, but they generally require fertilization with nitrogen salts. Most of the cereals, such as wheat, rye, oats, and barley, take up the principal part of their nitrogen early in the season, before the nitrification process has been sufficiently operative to furnish a large supply of nitrogen; hence nitrogen is the fertilizer constituent that usually gives the best results, and should be added in a soluble form. Wheat, in particular, needs a large amount of soluble nitrogen early in its spring growth. Since it is a "delicate feeder," it does best after a cultivated crop or a fallow, by which the nitrogen has been converted into a soluble form. Oats can make better use of the soil fertility and do not require so much manuring. Rye is a very coarse "feeder," and, while it removes a large quantity of plant-food from the soil, it does not require that this shall be added in a soluble form. From manure and other slowly soluble manures may well be applied for the main crop. The long growing period required by the winter plant gives it opportunity to utilize the nitrogen as it becomes avail-

able during the summer, when assimilation and nitrification are active. Phosphorus is the substance usually most needed by maize.

332. *The feeding of grass crops.*—Grasses, when in pasture or in pasture, are greatly benefited by manure. They are less vigorous "feeders" than the cereals, have deeper roots, and, when left down for more than one year, the lack of aeration in the soil causes decomposition to decrease. There is usually a more active fixation of nitrogen in grass lands than in cultivated lands, but this becomes available very slowly.

Different soils and different climatic conditions necessitate different methods of manuring for grass. More manures may well be applied to meadows in all situations, while the use of nitrogen is generally profitable.

333. *Leguminous crops.*—Most of the leguminous crops are deep-rooted and are vigorous "feeders." Their ability to take nitrogen from the air makes the use of that fertilizer unnecessary except in a few instances, such as young alfalfa on poor soil, where a small application of nitrate of soda is usually beneficial. There are no potassium are the substances most beneficial to legumes or the majority of soils.

334. *Root crops.*—Many root crops will utilize very large quantities of plant food if it is in a form in which they can use it. Phosphorus and nitrogen are the substances generally required, the latter especially by beets and carrots.

335. *Vegetables.*—In growing vegetables the object is to produce a rapid growth of leaves and stalks rather than roots, and often this growth is made very easily in the season. As a consequence, a notable loss of nitrogen is very desirable. Farm manure should also have a pre-

next part in the treatment, as it keeps the soil in a moisture condition favorable to retention of nutrients, which vegetables require in large amounts, and it also supplies needed fertility. The very intensive method of culture employed in the production of vegetables necessitates the use of much greater quantities of manures than are used for field crops, and the great value of the product justifies the practice.

325. *Practise*.—In manuring fruits, with the exception of some of the small rapidly-growing ones, it is the aim to maintain a continuous supply of nutrients available to the plant, but not sufficient for stimulation except during the early life of the tree, when rapid growth of wood is desired. An acre of apple trees in bearing requires as much plant-food material from the soil in a season as does an acre of wheat. Thus manure and a complete fertilizer may be used, of which the concentration should be in a fairly available form, as a constant supply is necessary. A young growing orchard requires considerably more nitrogen than does an old orchard. Some nitrate of soda in early spring is desirable.

326. *Mineral substances absorbed by plants*.—The plant, in its process of growth, withdraws from the soil certain mineral substances that are presented to its roots in a dissolved condition. As the salts in solution are rather numerous, and since the diffusion by which the absorption is accomplished does not select of the entire solution of any less capable of dissolving, there are to be found in the plant most of the mineral constituents of the soil. Some of these are essential to the vital processes of the plant and are essential to its growth; others seem to have no specific function, but are generally present. The substances commonly met with in the soil of plants

as potassium, sodium, calcium, magnesium, iron, manganese, aluminum, phosphorus, sulfur, silica, and chlorine. In addition to these, nitrogen is absorbed from the soil in the form of soluble salts. Of these the substances known to be absolutely essential to the normal growth of plants in nature, are potassium, sodium, magnesium, iron, phosphorus, sulfur, and nitrogen, while the others are probably beneficial to the plant in some way not yet determined.

If the substances acting as plant nutrients, such must be present in an amount sufficient to enable possibly the maximum growth consistent with other conditions, or the yield of the crop will be retarded by its deficiency. To some extent certain essential substances may be replaced by others, as, for instance, potassium by sodium; but such substitution is probably possible only in some physiological salt other than that of an elemental constituent of an organic compound. These substances that are likely to be so deficient, as an available form in any soil as to retard the yield of crops, are potassium, phosphorus, nitrogen, and possibly sulfur; while the addition of certain forms of sodium is likely to be beneficial because of its relation to other constituents and properties of the soil. It is for the purpose of supplying these substances, and to some extent to improve the mechanical condition of the soil, that mineral nutrients are used.

336. Relation of plant growth to concentration of nutrient solution. — (It has already been stated that the addition of soluble salts to a soil has been found by some experimenters to apparently increase the concentration of the soil solution (p. 210). It has also been found that plant growth, as measured by weight of plants, increases with the concentration of the nutrient solution in

which the plants are grown? This is the way in which it is generally believed that soluble fertilizers will benefit plant growth. Insoluble plant-food materials have a similar, but less active, result because they do not increase the concentration of the soil solution to an equal extent.

538. *Quantities of plant-food material removed by crops.*—The utilization of mineral substances by crops is a source of loss of fertility to agricultural soils. In a state of nature, the loss in this way is comparatively small, as the native vegetation falls on the ground, and in the process of decomposition the substances are entirely returned to the soil. Under natural conditions, soil usually becomes so fertile; for, while there is some loss through drainage and other causes, this is more than counterbalanced by the action of the natural agencies of disintegration and decomposition, and the fixation of atmospheric nitrogen effects a constant, though small, supply of that important soil ingredient.

When land is put under cultivation, a very different condition is presented. Crops are removed from the land, and only partially returned to it in manure or straw. This withdraws normally a certain small proportion of the total quantity of mineral substances, but, what is of more immediate importance, it withdraws all of this in a readily available form.

The following table, computed by Warington,¹ shows

¹1861. A. D. Trenchard, W. E. and Kirkwood, J. M. *The Soil Solution and the Mineral Constituents of the Soil*. Philadelphia: Trans. Royal Soc. London, Series B, Vol. 20, pp. 579-601. 1893. Also, Jones, T. J., and Steward, J. A. *The Food as an Indicator of the Soluble Constituents of Soil Solutions*. Proc. Am. Soc. Agres., Vol. 4, pp. 33-41. 1903.

²Warington, E. *Chemistry of the Soils*, pp. 16-66. New York, 1894.

for quantities of nitrogen, potassium, phosphorus, and for removal from an acre of soil by some of the common crops. The entire harvested crop is included:

| Crop | Yield | Per cent of soil | Per cent of soil | Per cent of soil | Per cent of soil |
|------------------|------------|---------------------|---------------------|---------------------|---------------------|
| | | 100 | 100 | 100 | 100 |
| Wheat | 30 bushels | 172 | 46 | 28.8 | 28.1 |
| Barley | 40 bushels | 187 | 48 | 30.7 | 30.7 |
| Oats | 15 bushels | 79 | 20 | 11.9 | 11.9 |
| Maize | 30 bushels | 171 | 43 | 36.1 | 36.1 |
| Wheat hay . . . | 15 tons | 312 | 49 | 33.1 | 33.1 |
| Red clover . . . | 5 tons | 288 | 362 | 35.4 | 35.4 |
| Peas | 6 tons | 337 | 47 | 36.5 | 36.5 |
| Turnips | 17 tons | 398 | 115 | 146.8 | 146.8 |

340. Quantities of plant-food materials contained in soils. — Comparing the figures given above with those showing the percentage of the fertilizing constituents in certain soils, it is evident that there is a supply in most soils which will afford nutriment for average crops for a very long period of time. (See pages 41, 42, 43, 44.)

341. Sustainable exhaustion of mineral nutrients. — On the other hand, when it is considered that the soil must be depended upon to furnish food for humanity and domestic animals as long as they shall continue to inhabit the earth, at least so far as is now known, the very remote possibility of exhaustion, even in a period of several hundred years, the supply of plant nutrients becomes a matter of grave concern. The visible sources of supply, to replace or supplement those in the soils now exhausted, are, for the mineral nutrients, the natural and the natural deposits of phosphates, potash salts, and

Atmosphere; and the various deposits of sediments, the products of dust, detritus, and the nitrogen of the atmosphere. The last of these is inestimable, and the utilization of the nitrogenogen, which a few years ago was thought to be a matter of less than half a century, has now ceased to be any more hypothetical. The nitrogenization or saturation of the supply of animal material is now of frequent importance. The utilization of city refuse and the discovery of new mineral deposits are developments well within the range of possibility, but neither of these promises to afford more than partial relief. The utilization of the animal through the gradual removal by natural agencies of the typical soil, without doubt, leads to conductivity means the supply. The removal of insects by wind and creation of insect on level land, a very considerable factor. The large amount of sediment carried in streams immediately after a rain, especially in streams, gives some idea of the extent of this plving. This affects clearly the surface soil, and thereby brings the animal into the range of most action.

There is little doubt that a moderate supply of plant-food materials will always be available in most soils, but for progressive agriculture measures must be used.

CHAPTER XI

ORGANISM IN THE SOIL

A vast number of organisms, animal and vegetable, live in the soil. By far the greater part of these belong to plant life, and these comprise the forms of greatest influence in producing the changes in structure and composition that contribute to soil productivity. Most of the organisms are so minute as to be seen only by the aid of the microscope, while a much smaller proportion range from those to the size of the larger rodents. They may thus be classed as microorganisms and macroorganisms. The latter class will be considered first.

MACROORGANISMS OF THE SOIL

If the macroorganisms in the soil the animal forms being chiefly (1) rodents, (2) worms, and (3) insects, and the plant forms in (1) the large fungi and (2) plant roots.

MO. Rodents.—The burrowing habits of rodents—of which the ground squirrel, the mole, the prairie dog, and the shrew are familiar examples—result in the pulverization and transfer of very considerable quantities of soil. While the activities of these animals are often not favorable to agriculture, the effect on the character of the soil is rather beneficial and is analogous to that of good tillage. Their burrows also serve to aerate and drain the soil, and

is permanent pasture and meadows are of much value in this way.

344. *Worms*.—The common earthworm is the most conspicuous example of the benefit that may accrue from this form of life. Darwin, as the result of careful investigation, states that the quantity of soil passed through these creatures may, in a favorable soil in a humid climate, amount to ten tons of dry earth per acre annually. The earthworm obtains its nourishment from the organic matter of the soil, but takes into its alimentary canal the inorganic matter as well, repelling the latter in the form of casts after it has passed entirely through the body. The rejected material is to some extent disintegrated, and is in a fertilized condition. The holes left in the soil serve to increase aeration and drainage, and the movements of the worms bring about a useful transportation of lower soil to the surface, which acts still more in effecting aeration. Darwin's studies led him to state that two root-tubs to two-tenths of an inch of soil is yearly brought to the surface of land in which earthworms exist in normal numbers.

Inclosures are on record of land flooded for a considerable period so that the worms were destroyed, and the productivity of the soil was seriously impaired until it was restocked with earthworms.

Woolly caterpillars ripenents with soil, the soil is also more containing earthworms and in another case not out-taking them. Although there was much variation in the results, they were in every case in favor of the soil containing the worms, and in a number of the tests the soil so rich soil was several times as great as where no worms were present.

Earthworms actually seek a heavy, compact soil, and

it is in soil of this character that they are most needed because of the stirring and aeration they accomplish. Sandy soil and the soils of arid regions, in which are found few or no earthworms, are not usually in need of their activities.

144. *Summits*.—There is a less definite, and probably less effective, action of a similar kind produced by insects, ants, beetles, and the myriads of other burrowing insects and their larvae effect a considerable movement of soil particles with a consequent aeration of the soil. At the same time they incorporate into the soil a considerable quantity of organic matter.

145. *Large fungi*.—The larger fungi are chiefly concerned in bringing about the first steps in the decomposition of woody matter, which is distinguished through the growth in its tissues of the root systems of the fungi. These break down the structure, and thus greatly facilitate the work of the decay bacteria. Action of this kind is largely confined to the forest and is not of great importance in cultivated soil.

Another function of the large fungi is carried in the lichens, and possibly symbiotic, relation of the fungus hyphae to the roots of many forest trees, in soil where mineralization proceeds very slowly. If at all, the situation is apparently not abundant in forest soils. This symbiotic system of hyphae, which may consist of masses in a definite case of the cortex with seasonal diametrically passing into the soil, or which may surround the root with a dense mass of interwoven hyphae, is called mycorrhiza.

The aerial, crustaceous, lignivorous, and subterranean fungi are not associated with mycorrhiza. Mycorrhizal plants are usually those that live in a barren soil (silica).

with the mycelia of fungi. It is thought that the mycorrhiza and the higher plants to obtain nutrient that they need strive for in competition with the fungi.

Myotrophic plants are also able to grow with a very small transpiration of moisture, as is well known to be the case with mossy confiers; and this restricted transpiration would doubtless result in lack of nutrient were it not for the assistance of the mycorrhizas.

Mo. Plant roots.—The roots of plants assist in promoting productivity of the soil both by maintaining organic matter and by leaving, as their decay, openings which render the soil more permeable to water and which also facilitate drainage and aeration. The dense mass of roots, with their minute hairs that are left in the soil after every harvest, furnish a well-distributed network of organic masses, which is not confined to the surface soil, as is artificially incorporated manures. The drainage and aeration of the lower soil, due to the openings left by the decomposed roots, are of the greatest importance in heavy soil, and the beneficial effects of dense and other deep-rooted plants are due in measure to this function.

MYCORRHIZAS OF THE SOIL.



FIG. 24.—Mycorrhizas growing on plant roots.

Of the mycorrhizas commonly existing in soils, the greater part belong to plants rather than to animal life. Of the latter, the only organisms of real interest are the nematodes (Fig. 24), whose injurious effect on plant growth is accomplished through the formation of galls on the roots, in which the young are hatched and live to great numbers.

547. *Plant microorganisms.*—The microscopic plants of the soil may be classed as algae, molds, bacteria, fungi, and algae.

548. *Plant microorganisms injurious to higher plants.*—Fungus plant microorganisms are confined mostly to large and herbaceous. They may be entirely parasitic in their habits, or only partially so. They injure plants by attacking the roots. Those that attack other parts of plants may live in the soil during their spore stage, but they are not strictly microorganisms of the soil. Some of the more common diseases produced by soil organisms are: wilt of cotton, sugarcane, watermelon, etc.; wilts, root-rot, and other plagues, damping-off of a large number of plants; root-rot, galls.

These fungi or bacteria may live for long periods, probably indefinitely, in the soil, if the conditions necessary for their growth are maintained. Some of them will die within a few years if their host plants are not grown on the soil, but others are able to maintain existence on almost any organic substance. Once a soil is infected, it is likely to remain so for a long time, or indeed indefinitely. Infection is easily carried. Soil from infected fields may be carried on implements, plants, or animals of any kind, in soil used for inoculation of leguminous crops, or even in stable manure containing infected plants or in the feces resulting from the feeding of infected plants.

Portage of land by which soil is washed from one field to another may be a means of infection.

Prevention is the best defense from diseases produced by these soil organisms. Once disease has passed a threshold, it is practically impossible to eradicate all its organisms. Rotation of crops is effective for some diseases, but entire absence of the host crop is of more conse-

may. The use of lime is beneficial in the case of certain diseases. Chemicals of various kinds have been tried with little success. Steam sterilization is a promising method of treating greenhouse soils for a number of diseases. The breeding of plants immune to the diseases of fungi in particular species has been successfully carried out in the case of the corn and cotton plants, and can doubtless be accomplished with others.

In regions in which farming is confined largely to one crop or to a limited number of cereals, it is the common experience that yields decrease greatly in the course of a series of years after the virgin soil is broken. The cause for this is attributed by Bailey¹ to large measure to a diseased condition of the plants due to the growth of various fungi that inhabit the soil and attack the crop grown on it. He reports that he has experimented with pure cultures taken from wheat, grain, clover, and roots, and has demonstrated that certain strains or species of *Ascarium*, *Heterodermium*, *Monosorus*, *Macromonosorus*, *Colletotrichum*, and *Ophiostoma* are directly capable of attacking and destroying growing plants of wheat, oats, barley, house grass, and quack grass, and that within limits the disease may be transferred from one type of crop to another.

349. Plant microorganisms not injurious to higher plants.—The vegetable microorganisms of the soil all take an active part in removing dead plants and animals from the surface of the soil and in bringing about the other operations that are necessary for the production of plants. The first step in the preparation for plant growth is to remove the remains of plants and animals that would

¹Bailey, H. T. "Wheat." North Dakota Agr. Exp. Sta. Bul. 107, 1913.

otherwise succumb to the exclusion of other plants. These are decomposed through the action of organisms of various kinds, the intermediate and final products of decomposition assisting plant production by contributing nitrogen and certain mineral compounds that are directly available sources of plant nutriment, and also by the effect of certain of the decomposition products on the general substances of the soil, by which they are rendered soluble and hence available to the plant.

Through these operations the supply of carbon and nitrogen required for the production of organic matter is kept in circulation. The simplest organic compounds in the bodies of dead plants or animals, in which condition plants cannot use them, are, under the action of microorganisms, converted by a number of stages into the very simple compounds used by plants. In the course of this process a part of the nitrogen is sometimes lost into the air by conversion into free nitrogen, but fortunately this may be recovered and even more nitrogen takes from the air by certain other organisms of the soil.

The clove mite, bacteria, fungi, and algae all play a part in these processes, but none of them so actively during every stage of the processes as do the bacteria. Molds and fungi are particularly active in the early stages of decomposition of both nitrogenous and non-nitrogenous organic matter. Molds are also capable of assimilating proteins, and even reforming the complex protein bodies from the nitrogen of ammonium salts. Certain of the molds and of the algae are apparently able to fix atmospheric nitrogen, and contribute a supply of nitrates and nitrites for the use of the nitrifying bacteria. Among these are *Aspergillus niger* and *Penicillium glaucum*.

It also seems probable that the fungi associated with

the roots of many forest trees and lawns, as saprophytes, have the ability to fix atmospheric nitrogen, and that in some way the trees obtain a part, at least, of the nitrogen so fixed. The growth of forests on poor, sandy soil containing practically no nitrogen has been used as an example of this process.

383. **Bacteria.**—Of the several forms of saprophytous forms found in the soil, bacteria are the most important. In fact, the abundant and continued growth of plants on charcoal is absolutely dependent on the presence of bacteria, for through their action chemical changes are brought about which result in making soluble both organic and inorganic material necessary for the life of higher plants, and which, in part at least, would not otherwise occur.

Bacteria are thus true lawns, not producers, of fertility in the soil, although, as will be seen later, certain kinds of bacteria take nitrogen from the air and leave it in the soil. With this exception, however, they add no plant-food to the soil. It is their action in rendering available to the plant material already present in the soil that constitutes their greatest present value in crop production. It is in their activity in converting nitrogen from the air to the soil that we are inhibited for most of our supply of nitrogen in virgin soils (see Fig. 39).



FIG. 39.—Some typical soil microorganisms supply nutrients. (A) Nitrate bacteria; (B) nitrifying bacteria; (C) nitrifying bacteria; (D) nitrifying bacteria; (E) nitrifying bacteria; (F) nitrifying bacteria; (G) nitrifying bacteria; (H) nitrifying bacteria.

that we are inhibited for most of our supply of nitrogen in virgin soils (see Fig. 39).

It is not usually the entire absence of bacteria from the soil that is to be avoided in practice, for all viable soils contain bacteria, although sometimes not all of the desirable forms; but, as great bacterial activity is required for the large production of crops, the practical problem is to attain a condition of soil most favorable to such activity.

831. *Distribution of bacteria.*—Bacteria are found almost universally in soils, although they are much more numerous in some soils than in others. A number of investigators have stated that in soils from different localities and of different types that they have examined, the numbers of bacteria were proportional to the productivity of the soils. The number of bacteria present has in some cases been shown to be proportional to the amount of humus contained in the soil. It is natural to expect that within certain limits both these findings will hold. The conditions obtaining in a good soil are such as are favorable to the development of certain forms of bacteria, and these forms constitute a very large proportion of those generally found in soils. However, there is evidence that unproductively unproductive soils may contain a large number of bacteria that are presumably not favorable to plant growth.

Samples of soil taken from certain productive and relatively unproductive parts of a field on the Cornell University farm contained a larger number of bacteria in the poor soil, although the two soils were equally well drained and the good soil had slightly more organic matter. They had also received practically the same treatment during the preceding few years:—

| Character of soil | Number of bacteria per gram of dry soil |
|-------------------|---|
| Good | 1,200,000 |
| Poor | 1,800,000 |

After wheat had been growing for two months on these soils in the greenhouse, the soils being maintained at the same moisture content, the samples showed the following result:—

| Character of soil | Number of bacteria to a gram of dry soil |
|-------------------|--|
| Good | 760,000 |
| Poor | 1,120,000 |

Another reason why this relation between the number of bacteria and soil productivity does not hold is that the bacteria having the same function in relation to plants do not always have the same physiological efficiency. In other words, they do not have the same virulence, a small number in some cases being able to bring about the same changes that in other cases require a much greater number.

Bacteria are found chiefly in the upper layers of soil, although not in large numbers at the immediate surface of the ground. In humid regions the layer between the first inch and the sixth or the seventh inch contains, in most soils, the great bulk of bacteria present. In arid or semiarid regions, bacteria are found at greater depths and the densest population is located at lower levels than in humid regions. This is largely because of the deeper penetration of the air and the conditions that accompany it.

362. *Number of bacteria.*—The number of bacteria in a soil will naturally vary with the conditions that favor or discourage their growth. In very sandy soils, hence soils desert soils, water-logged soils, and soils low in humus, the bacteria are either absent or comparatively few in numbers. In soils very rich in organic matter, especially

plant animal manure has been applied or when a course has been buried, the number becomes very large, as easily as 20,000,000 in a gram of soil having been found, while in soil of ordinary fertility and with the same very range from 1,000,000 to 5,000,000 per gram. The extreme equality with which reproduction occurs makes it possible for the number to increase enormously when conditions are favorable for their growth.

The table on page 432 shows the number of bacteria in a gram of soil found in different parts of the United States during some portion of the growing season.

The figures showing the number of bacteria in each gram of soil that are presented in this table cannot be used for a comparison of the relative number of bacteria in soils of different regions of this country, because different methods were used by the experimenters in making the estimations. They are, however, an indication of what may be considered the ordinary range in viable cells.

88. *Numbers as influenced by season.*—It might be supposed that, like most plants, bacteria would develop most rapidly in summer months and that they would be found in largest numbers at that season, at least in regions of low temperature during the winter months. That this is not always the case has been shown by Cress¹ (the land as the result of practical observation of bacteria throughout a term of two years that the highest counts were obtained during the winter months, when the soil was frozen. This does not mean that all classes of bacteria are present in largest numbers at that season, but, as explained by Cress, it seems likely that certain

¹Cress, E. J. Bacteria in *Prison* 10. *Genetics* 1. *Ann.*, 11, *Nov.* 12, 1902, 76-87.

USE VALUE: PROPORTION AND MANAGEMENT

MINUTES OF MEETINGS OF A GROUP OF RESEARCHERS
 FROM THE UNIVERSITY OF

| Ref. | No. | Order | Date | Location | Value |
|--------|----------|-------|------------------|----------|-----------|
| Debate | Ref. 100 | 1 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 2 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 3 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 4 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 5 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 6 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 7 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 8 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 9 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 10 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 11 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 12 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 13 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 14 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 15 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 16 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 17 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 18 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 19 | October 10, 1910 | Chicago | 1,000,000 |
| Debate | Ref. 100 | 20 | October 10, 1910 | Chicago | 1,000,000 |

1. Chicago, N. D., The Biological Analysis of the
 University of Chicago, Vol. 10, 1910.
 2. Mayo, T. S., and Keady, A. F. The Biology of the
 University of Chicago, Vol. 11, 1911.
 3. Mayo, T. S., and Keady, A. F. The Biology of the
 University of Chicago, Vol. 12, 1912.

from producers in summer and others in winter (see Fig. 19).

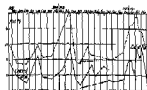


FIG. 19.—Predicted succession of bacteria in soil of very poor fertility two years, expressed in millions to a gram of dry soil.

Dryden and Smith¹ obtained results that in the main confirmed Conn's work, and they advanced the theory that the concentration of the soil solution immediately surrounding the soil particles, together with the high surface tension exerted by the soil particles, prevents the flowing of the surface film and that this water forms a suitable medium for the development of bacteria.

364. *Conditions affecting growth.*—Many conditions of the soil affect the growth of bacteria. Among the most important of these are the supply of oxygen and moisture, the temperature, the presence of organic matter, and the acidity or the basicity of the soil.

365. *Oxygen.* All soil bacteria require for their growth a certain amount of oxygen. Some bacteria, however, can maintain their activities with much less oxygen than can others. Those requiring an abundant supply of oxygen have been called aerobic bacteria, while those preferring little or no air are designated as anaerobic.

¹ Brown, P. R., and Smith, A. R. *Bacterial Infection in Plants and Soils*. New York: McGraw-Hill, 1913.

bacteria. This is an important distinction, because those bacteria that are of the greatest benefit to the soil are, in the main, aerobic, and those that are injurious in their action are chiefly anaerobic. However, it seems likely that an aerobic bacterium may gradually accommodate itself while certain fluids in its environment containing less oxygen, and an anaerobic bacterium may accommodate itself to the presence of a larger amount of oxygen. Thus a bacterium may be most active in the presence of an abundant supply of oxygen, but, when subjected to conditions in which the supply is small, growth continues but with lessened vigor. The term *facultative bacteria* has been used to designate those bacteria that are able to adapt themselves to considerable variations in oxygen supply. The structure, tilth, and drainage of the soil consequently determine largely whether aerobic or anaerobic bacteria shall be more active.

36. Moisture.—Bacteria require some moisture for their growth. A notable decrease in the moisture content of the soil may temporarily decrease the number of bacteria by limiting their development to the film of moisture surrounding the particles. With a decrease in the moisture content of a soil, there occurs an increase in the oxygen in the interstitial spaces. Those bacteria that thrive in the presence of oxygen are thereby favored, and the character of the bacterial flora is correspondingly changed. When the soil remains saturated, or nearly so, for any considerable period, the anaerobic forms assert themselves, and the usually beneficial activities of the aerobic bacteria are temporarily suspended. The most favorable moisture condition for the activity of the most desirable bacteria is that found in a well-drained soil.

33. *Temperature*.—Soil bacteria, like other plants, outline life and growth under a considerable range of temperatures. Freezing, while rendering bacteria dormant, does not kill them, and growth begins slightly above that point. It has been shown that crystallization goes on at temperatures as low as 32° to 33° F. It is not, however, until the temperature is considerably higher that their functions are pronounced. From 70° to 110° F. their activity is greatest, and it characteristically begins to fall at lower than these points. The thermal death point of most forms of bacteria is found at some point between 170° and 180° F., but the spore forms may resist boiling. Only in some desert soils does the natural temperature reach a point sufficiently high to actually destroy bacteria, and then only near the surface. In fact, it is known that soil temperatures become sufficiently high to control bacterial activity.

34. *Organic matter*.—The presence of a certain amount of organic matter is essential to the growth of not, but not all, forms of soil bacteria. The organic matter of the soil, consisting as it does of the remains of a large variety of substances, furnishes a suitable food supply for a very great number of forms of organisms. The action of one set of bacteria on the cellular matter of plants embedded in the soil produces compounds useful to other forms, and so from one stage of decomposition to another this constantly changing material affords sustenance to a bacterial flora the extent and variety of which it is difficult to conceive. Not only do bacteria affect the organic matter of the soil, but, in the case of certain forms, their activities produce changes in the inorganic matter that cause it to become more soluble and more easily available to the plant.

A soil low in organic matter usually has a lower bacterial content than one containing a larger amount, and, under favorable conditions, the bacterial action, to a certain point at least, increases with the content of organic substances; but, as the products of bacterial life are generally injurious to the organisms producing them, such factors as the rate of aeration and the acidity of the soil must determine the effectiveness of the organic matter.

100. Soil acidity. — A soil having an acid reaction makes a poor medium for the growth of certain bacteria. A neutral or a slightly alkaline soil furnishes the most favorable conditions for the development of the forms of bacteria most beneficial to agriculture. The activities of many soil bacteria result in the formation of acids which are injurious to the bacteria themselves, and, unless there is present some basic substance with which these are combined, bacterial development is inhibited by their own products. This is one of the reasons why lime is so often of great benefit when applied to soils, and especially to those on which alfalfa and red clover are growing. For the same reason, the presence of lime hinders decay of organic matter in certain soils, and the conversion of nitrogen material into a minimum loss into compounds available to the plants. As showing the value of lime in the process of nitrate formation, it has been pointed out that in the presence of an adequate supply of lime the availability of ammonium salts is almost as high as that of nitrate salts, but when the supply of lime is insufficient the value of ammonium salts is relatively rather low.

101. Functions of soil bacteria. — Bacteria have a part in many of the processes of the soil which greatly affect

in productivity. It has become customary to refer to the changes produced by various forms of bacteria as their *action* or *contributing to soil productivity*.

34. *Decomposition of mineral matter*.—Certain bacteria decompose some of the mineral matter of the soil and render it more easily available to the plant. While the nature of the processes and their extent are not known, there is sufficient evidence to justify the above statement. It is well known that several kinds of bacteria are instrumental in decomposing rock, and that sulfur and iron compounds are acted upon by other forms.

To what extent the very difficultly soluble forms of phosphorus, as tricalcium phosphate, for example, are rendered soluble and available to agricultural plants by microorganisms, is a matter of great importance. The extent to which the subject has been investigated is rather limited, but, in the main, there is indicated a considerable action of both bacteria and fungi on tricalcium phosphate.

35. *Influence of certain bacteria and molds on the solubility of phosphates*.—Some very significant experiments were conducted by Stickman, Hudonick, and Pines.¹ They found that, when brought into contact with pure cultures of certain bacteria, was apparently rendered soluble, the extent to which the solubility increased varying with the different strains of bacteria brought into contact with it. The percentage of the total tricalcium phosphate in the soil that was rendered soluble was as follows:—

¹ Stickman, J., Hudonick, P., and Pines, J. *Ueber den Einfluss der Bakterien auf die Löslichkeit von Phosphorsäure*. *Centralbl. f. Bakt.*, C. Band 10, Heft 198-205, 206-209. 1906.

| | Per cent |
|---|----------|
| Not inoculated | 3.83 |
| <i>B. megaterium</i> | 21.25 |
| <i>B. thuringiensis</i> | 30.19 |
| <i>B. pasteurii</i> vulgaris | 14.71 |
| <i>B. thuringiensis</i> Illigge | 15.53 |
| <i>B. megaterium</i> | 23.06 |
| <i>B. thuringiensis</i> | 23.60 |

Lieber's paper gives a hint to have found the *Agrobacterium* species, *Proteobium* species, and *P. thuringiensis*, isolated from garden soil, when placed in nutrient solution with tricalcium phosphate, neutralized one-third to one-half of the phosphate in sixty days.

There is some difference of opinion whether the solvent action arising from bacterial growth is due entirely to the acids that are produced by the bacteria, exerting such action, or whether there is also some other influence exerted by bacteria. Stoklas, however, for the solvent action of the bacteria in his experiments by the bacterial action of *proteobium* and *thuringiensis* species acting on the bone meal. In opposition to this idea, Lieber¹ maintains that the solvent action depends on the kind of fermentation that the organic matter undergoes, and fermentation rendering the phosphate more soluble, with ammonium fermentation results in no solvent action on tricalcium phosphate salt, in the presence of sufficient basic material, may render the phosphorus and fixed

¹ Lieber, P. Handbuch d. Landw. Bakteriologie, 869-871 Berlin, 1910.

² Lieber, P. Über die Löslichkeit der Phosphorsalze von Ammoniakalischen Fermenten unter der Einwirkung von Harnsäure und Lysin. Jour. f. Landw., Band 57, Seite 5-61 1905-1910.

more phosphates available. He would limit the solvent action of bacteria to the effect of the acids they produce. Sackett, Carter, and Brown have in a manner repeated Saksena's experiments and obtained somewhat similar results, which lead them to conclude that there is a solvent agent other than the acids produced by the bacteria.

It would appear from these experiments that bacteria, and possibly fungi, commonly found in soils act on insoluble phosphate in such a manner as to render a part of it available. Nevertheless, experiments that have been conducted for the purpose of ascertaining whether the action of plants in soils is rendered more easily available to plants when large quantities of decomposing organic matter are present than when this is not the case, have not, in the main, indicated that the decomposing organic matter increases availability of the phosphorus (p. 435). An explanation of this may possibly be found in the occurrence of a reverse biological process which results in the transformation of available phosphates into insoluble ones, the occurrence of such a process having been noted by Saksena¹ and others.

The carbon dioxide produced by bacteria is a solvent for many of the minerals of the soil, and may free calcium and potassium from insoluble salts and silicates.

Various groups of soil bacteria, through the production of H_2S and H_2SO_4 , act on iron in the soil and convert it into soluble and sulfate. Carbon dioxide also

¹ Saksena, R. C., Prasad, A. J., and Brown, C. W. The Mutual Action of Soil Bacteria upon the Insoluble Phosphates of New Bone Meal and Various Rock Phosphates. *Vegetation Soc. Roy. Soc. Canada Bull.* 41, 1928.

² Saksena, J. *Erkenntnis der Pflanzenernährung in Indien*. *Central J. Soil, II*, Band 25, 269-280-1923.

plays a part in the solution of iron. The lower fungi and the algae precipitate iron from solution as iron sulfide.

323. Decomposition of non-nitrogenous organic matter.

—The organic matter commonly encountered in soils contains a large proportion of compounds containing no nitrogen. Many non-nitrogenous substances decompose rather rapidly, and the organic nitrogen decomposes less rapidly than the carbon, hydrogen, and oxygen of organic bodies.

Humus always contains a higher percentage of nitrogen than do the plants from which it is formed.

The non-nitrogenous substances consist of cellulose and allied compounds forming the cell walls of plants, and the carbohydrates, organic acids, fats, and the like, contained in them. The dissolution of cellulose is brought about by the action of the enzyme *cellulase* secreted by a number of fungi, and is also probably accomplished by the *Streptomyces* mycelium, but whether through the secretion of an enzyme is not known. *Ustilago* spores have been reported to secrete a *cellulase* that acts on certain constituents of the cell wall. It is probable that numerous organisms capable of fermenting cellulose and allied substances exist in the soil, accomplishing this decomposition through the production of *cellulase*.

The effect of *cellulase* on cellulose and other fiber is to hydrolyze it with the formation of sugar, as glucose, mannose, xylose, xanthine, and the like.

Starch is converted into glucose by a ferment (diastase) either present in the plant itself or possibly secreted by fungi or bacteria. All the sugars are finally converted into organic acids which may combine with mineral bases. Different organisms have been isolated that can differ for their development, tolerance, resistance, propensities

hydrogen, and the final product being carbon dioxide and water. Thus, step by step, the non-organic matter incorporated with the soil is carried by one and another form of organism from the most complex to the simplest combinations.

The final product of the decomposition of carbonaceous matter being carbon dioxide, there is a return to the air of the compound from which the carbon of the decomposing substance was originally derived. In the plant, unless it is magnesian, the carbon of the tissues comes largely from the carbon dioxide of the air, from which were made the carbon-bearing compounds are produced and utilized in its formation or in its tissues. A portion of the carbon is returned to the air by the plant in the form of carbon dioxide; the remainder is retained by the plant, and may be returned by the process of decay or may be consumed by an animal, and, as the result of its physiological processes, either retained as carbon dioxide or deposited in the tissues to be later decomposed and converted into carbon dioxide. The soil is thus the scene of at least a part of the varied transformations through which carbon is continually passing as it is utilized by higher plants, animals, bacteria, and fungi.

The non-nitrogenous organic substances in their various stages furnish food for a large number of bacteria, among which are those concerned in the decomposition of animal matter and in the processes of nitrification and nitrogen fixation. These are, therefore, two ways in which these substances are of great importance in soil fertility: (1) as a source of carbon dioxide and of organic acids; (2) as a food supply for useful soil bacteria.

3d. Decomposition of nitrogenous organic matter.—The decomposition of nitrogenous organic matter is so-

completed by a series of changes from one compound to another, as you saw to be the case with the overdeveloped materials. The final products are nitrates directly, water, usually some hydrocarbon gases resulting from the carbon and hydrogen of the organic matter, and also some hydrogen sulfide or other gas containing sulfur or a fixed combination of the sulfur of the proteins into sulfides; while the nitrogen is ultimately converted into nitrates, or into free nitrogen, although a portion of the original nitrogen sometimes escapes into the air in the intermediate stage, sometimes.

The processes will be discussed under the following heads, which represent certain more or less definite steps in the decomposition: 1, decay and putrefaction; 2, ammonification; 3, nitrification; 4, denitrification; 5, loss from atmospheric nitrogen. These various processes form what has been termed the nitrogen cycle.

CHAPTER XXI

THE NITROGEN CYCLE

Of the various elements composing the extracts used by plants, nitrogen has the highest economical value. It is, moreover, absorbed in large quantities by agricultural plants and the supply is consequently liable to loss in drainage water and in the gaseous form. Its importance to agriculture has led to much study of its occurrence, circulation, reactions, and movement in the soil.

When it is recalled that the nitrogen gas of the atmosphere is the original source of the world's supply of nitrogen, it becomes apparent that the agencies that have been instrumental in its transfer from one condition to another have been extremely active. The movement of nitrogen from air to soil, from soil to plant, from plant back to soil or to animal, and from animal back to soil, with a return to air at various stages, involves many lines, many factors, many organisms, and many reactions.

36. *Decay and putrefaction.*—Decomposition of the nitrogenous organic matter of the soil, occurring largely at the junction, begins with either one of two processes—decay or putrefaction. Decay is produced by aerobic bacteria, and naturally occurs when the conditions are favorable for their development. When the conditions are otherwise, the growth of these bacteria is checked, and then further decomposition would be extremely slow

more it is not for the other process—putrefaction. Putrefaction is produced by *anaerobic bacteria*. In the majority, and consequently in the *manure soil*, decay and putrefaction may be in progress simultaneously, decay taking place on the outside and on the surface of other parts, exposed to the air, while putrefaction occurs on the interior, where the supply of oxygen is limited. By reason of the two processes, decomposition is greatly facilitated.

Decay (see Fig. 64) produces a very rapid and complete decomposition of the substance in which it operates, most of the carbon and hydrogen being quickly converted into carbon dioxide and water, and the nitrogen into ammonia and probably some free nitrogen. The latter is possibly due to the action of bacteria, thus



The nature of the protein finally appears in the form of *nitrate*.

What the intermediate products are has not been determined, but in the decay of meat, in which there was an abundant supply of oxygen, urea, uric acid, polyacetic acid, and phenyl-pyruvic acids have been found.

Putrefaction results in a large number of complex intermediate compounds and proceeds much more slowly. Many of the substances thus produced are highly poisonous, and some of them have a very offensive odor. They may be further broken down by decay when the conditions are suitable, or by a continuation of the process of putrefaction. In either case, the poisonous properties and the odor are removed.

In the process of decomposition of organic matter two classes of substances are produced: (1) those that have been essential or essential to the bacteria, and therefore

have passed through the metabolic processes of the organism; (2) those that have been formed because of the arrival of certain atoms by bacteria or organisms from elsewhere, thus necessitating a transportation of the existing atoms and the consequent formation of a new compound.

Putrefaction is carried on by a large number of forms of bacteria, the resulting products depending on the substratum, the process of decomposition and on the bacteria involved. Some of the characteristic, although not constant, products formed in the putrefaction of albumin and proteins are ammoniac, putrescine, and volatile acids, followed by the formation of carbonates, pyrazine, skatol, and indol. Where an abundant supply of oxygen is present, or where a sufficient supply of oxyhydrolysis exist, these substances are not formed. There are many other products of putrefaction, including a number of gases, as carbon dioxide, hydrogen sulfide, marsh gas, phosphine, hydrogen, nitrogen, and the like.

It will be noticed that these changes, like those occurring in the non-symbiotic organic matter, involve a breaking-down of the more complex compounds and the formation of simpler ones; and that a very large number of bacteria are concerned in the various steps, while even the same substances may be decomposed and the same resulting compounds formed by a number of different species of bacteria.

Present-day knowledge of the subject does not enable it possible to present a list of the bacteria concerned in each step, or to name all the intermediate products formed; but for the student of the soil the practical consideration is a knowledge of the circumstances under which the nitrogen is made available to plants, and the

conditions that are likely to result is far less than the 101.

86. *Ammonification.*¹ Decay and putrefaction may be considered as the beginning of the process of ammonification. Ammonification, say (Fig. 41), in its more implicit is that stage of the process during which ammonia is formed from the intermediate products.

Like the other processes of decomposition, there are many species of bacteria capable of forming ammonia from nitrogenous organic substances. Different forms display different abilities in converting nitrogen of the same organic material into ammonia, some acting more rapidly or more thoroughly than others. In tests by certain investigators in which the same bacteria are used on different substances, the order of their efficiency is changed with the change of substance. It seems likely, therefore, that certain forms are more efficient when acting on certain organic compounds; that, in other words, each species is best adapted to the decomposition of certain substances, while capable of attacking others although less effectively. The characteristic preference of a class of bacteria for the decomposition of certain substances is made evident by the experiments of Sackett² who found that in some soils dried blood was decomposed more rapidly than was undried meat, whilst in other soils the reverse was true.

87. *Bactericidal substances associated in manure-fermentation.*—Among the bacteria producing ammonification are *B. saproducta*, *B. subtilis*, *B. pasteuriana* subsp. *B. pasteuris*, and *B. proteus vulgaris*. Of these *B. mycoides* has been very carefully studied, and the

¹ Sackett, W. C., The Ammonifying Efficiency of Certain Colorado Soils. Colorado Agr. Exp. Sta., Bul. 184, 1912.

believe of Marshall¹ may be taken as representative of the process of assimilation. He found that when the bacteria was added to a neutral solution of albumin, ammonia and carbon dioxide were produced, together with small amounts of pyruvic, lactic, tyrosine, and formic, lactic, and propionic acids. He concludes that in the process, atmospheric oxygen is used, and that the carbon of the albumin is converted into carbon dioxide, the sulfur into sulfuric acid, and the hydrogen partly into water, and partly into ammonia by combining with the nitrogen of the organic substance. He suggests that a complete decomposition of the albumin occurs according to the following reaction:—



The greatest activity occurred at a temperature of 90° F. and as low as 10° F. action was rather strong. Access of an increased amount of air, produced by increasing the surface of the liquid, increased the rate of assimilation. A slightly acid reaction in the liquid produced the maximum activity, but in a neutral or even slightly acid medium the process was continued, although much less actively.

Marshall found that *B. agrippae* was also capable of assimilating casein, fibrin, legumin, gelatin, myosin, serin, peptone, creatine, leucine, tyrosine, and aspartate, but not urea.

32. Nitrobacteria.—Some specialized plants can utilize nitrate as a source of nitrogen. This has

¹Marshall, B. *Sur la Production de l'Ammoniaque dans le Sol par les Bactéries*. *Bulletin de l'Académie des Sciences de Paris*, 1904, 7, 25, pp. 775-776. 1906.

been determined for maize, rice, peas, barley, and potatoes. Other plants, such as beets, show a decided preference for nitrate in the form of nitrate. Whether any of the common crops can fix air as well as some non-crops, as in nitrate, has not been finally determined. In most arable soils the transformation of nitrate does not stop with its conversion into ammonia, but goes on by an oxidation process to the formation of nit nitrous acid (see Fig. 44). This may be considered in general according to the following equation:—



The acid so nitrous acid combines with one of the bases of the soil, usually calcium, so that nitrate nitrate results.

Each of these steps is brought about by a distinct bacterium, but the bacteria are slightly mixed. Collectively they are called nitrobacteria. Nitrosomonas and Nitrosococcus are the bacteria concerned in the conversion of ammonia into nitrous acid or nitrite. The former are supposed to be characteristic of European, and the latter of American, soils. They are sometimes referred to as nitrate formers.

Nitrobacter are those bacteria that convert nitrite into nitrate. They are also designated nitrate formers. There seems to be some difference in bacteria from different soils, but the differences are slight and the conditions favoring the action of the bacteria are similar. It is also true that the conditions favoring the action of Nitrosomonas and Nitrobacter are similar, and they are generally found in the same soils, although some

experiments show that in the same soil nitrites may sometimes accumulate, indicating conditions more favorable to the development of the *Difflugianus* bacteria.

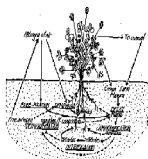


FIG. 11.—Diagrammatic representation of the nitrogen cycle in a soil profile. The diagram shows the various processes of nitrogen transformation in the soil.

The formation of nitrites usually follows closely on the production of nitrites, as that there is rarely more than a trace of the latter to be found in soils. A soil favorable to the process of nitrification is usually well adapted to all the processes of nitrogen transformation.

Natural differences have been found in the nitrifying power of bacteria from different soils. Highly productive soils have generally been found to contain bacteria having greater nitrifying efficiency than those from less productive soils, but this may not always be the case, as other factors may limit the productivity.

Effect of organic matter on nitrification.—A preliminary in the artificial culture of nitrifying bacteria

is that they cannot be grown in artificial media containing organic matter. This property for a long time prevented the isolation and identification of these organisms, as it was hardly conceivable that organisms living in the dark, where energy cannot be obtained from sunlight, could exist without using the energy stored by organic matter. It has been suggested, in explanation of this, that the energy produced by the oxidation involved in the process of vitellinization enables possible the growth of the organisms under those apparently impossible conditions. Some experimenters report having grown riboflavinin in inorganic media, but it is generally believed at present that this is not possible and that there has been some error in the work of those experimenters.

The presence of peptone in the proportion of 100 parts per million completely prevents the development of riboflavinin, and one-half that quantity checks it, while 100 parts of sucrose to the million has a similar effect. In a normal soil the quantity of soluble ammonium salts is well below this amount, as must also be that of soluble organic matter. In confirmation of the inhibiting effect of organic matter on the riboflavinin, cases have been reported of soils very rich in organic matter in which no bacteria of this type exist.

It has also been stated that very heavy manuring with organic manures results in decreased chlorination in the soil. While this may be true where farm manure is used in the quantities sometimes applied in gardening operations, it is not likely to be the case in soils in which ordinary field crops are grown. The principle is not illustrated by the dry earth chest. Manure mixed with earth in relatively small proportions and kept above by continual turning undergoes a very thorough decay

portion of the manure but without any corresponding increase in nitrate. On the other hand, under field conditions, manure used in relatively small amounts does not increase the nitrate loss.

The application of twenty tons of farm manure to the garden soil in a dry year and for three consecutive years, at Cornell University, resulted in a larger production of nitrate in the covered soil than on a corresponding plot of similar soil left unmanured. This was true during the first year of the applications, when the land was in rest, and also during the fourth year, when no manure was applied in either plot and when both plots were planted in corn, as may be seen from the following table:

MANURE PRODUCTION OF NITRATE MANURE AND OF THE GARDEN SOIL.

| | GARDEN SOIL | |
|---------------------|----------------|---|
| | Unmanured soil | Twenty tons manure/acre for three years |
| Soil in rest only | | |
| April 23 | 0.5 | 21.0 |
| May 2 | 4.2 | 4.6 |
| May 16 | 2.2 | 4.5 |
| May 29 | 1.0 | 4.0 |
| June 1 | 2.4 | 2.0 |
| June 15 | 0.8 | 1.1 |
| June 29 | 1.3 | 3.0 |
| July 14 | 5.2 | 2.8 |
| August 14 | 1.8 | 3.0 |
| Soil in corn | | |
| May 29 | 17.5 | 20.1 |
| June 12 | 43.8 | 19.3 |
| July 7 | 50.0 | 29.0 |
| July 26 | 126.0 | 80.0 |
| August 20 | 151.0 | 116.0 |

290. Effect of soil aeration on nitrification. — Probably the most potent factor governing nitrification in the soil is the supply of air. In clay, and even in heavy soils, the tendency to compaction is such as to prevent the passage of sufficient air to enable nitrification to proceed as rapidly as desirable unless the soil is well tilled. Columns of soil eight inches in diameter and eight inches in depth were removed from a field of clay loam on the General University farm, and carried to the greenhouse with out disturbing the structure of the soil as it existed in the field. At the same time, vessels of similar size were filled with soil dug from a spot near by. These may be termed untreated and treated soils. Both were kept at the same temperature and moisture content in the greenhouse, but no plants were grown on them. The production of nitrate was as follows:—

| Time in Greenhouse | Nitrate in One Pint, Free to one Molecule | |
|-------------------------------------|---|--------------|
| | Untreated soil | Treated soil |
| Wine taken from field | 5.2 | 12 |
| After standing one month | 6.2 | 17.5 |
| After standing two months | 8.0 | 45.8 |

301. Effect of seed on nitrification. — Manure and peat are used on land, especially if the soil is heavy. On the same type of soil as that used in the experiment last described, the average quantities of nitrate for each month of the growing season in the surface eight inches of soil here, as compared with twice that under the same conditions, were as follows:—

| Dates | Amount in Dry Res. From to the Machine | |
|------------------|---|------------|
| | Pounds | Wet Pounds |
| April | 1.9 | — |
| May | 1.0 | 17.1 |
| June | 5.1 | 62.2 |
| July | 4.0 | 106.9 |
| August | 5.6 | 132.7 |

The amount of nitrogen removed by the main crop was greater than that removed by the harvest; consequently the greater amount in the former will most be due to the effect of the crop.

As far as the conservation of nitrogen is concerned, not in an ideal way, for nitrides are formed very little faster than they are used, and are not carried off in large quantities by the drainage water.

In the corn land as much as 175 pounds of nitrate nitrogen was present in the first twelve inches of one acre, or fully three times as much as was used by the crop.

172. *Depth at which nitrate nitrogen takes place.*—(Worthington)¹ concluded from his experiments that nitrate nitrogen plants only in the surface six feet of soil. Hall² has pointed to the fact that no more nitrides were loaded from the 16-inch cylinder at Harland's than from the six-40 inches deep; which is very good evidence that in

¹Worthington, J. On the Distribution of the Nitrate Nitrogen in the Soil. Trans. Chem. Soc. Vol. 51, p. 105, 1907.

²Hall, A. B. The Book of the Nitrogenous Fertilizers, p. 221. New York, 1905.

that particular soil nitrification does not take place below 40 inches from the surface. In more porous soils, *however*, nitrification probably extends deeper, especially in the oxidized porous subsoils of soil and mineral regions. In all probability, nitrification is largely confined to the furrow slices, where the springing-up of the soil by tilage has provided the necessary air, and where the temperature rises to a point more favorable to the action of nitrifying bacteria. The results from the aerated and unsaturated soils as shown above represent the differences that doubtless exist between the furrow slice and the subsoil as far as nitrification is concerned.

193. Loss of silicate from the soil.—Nitrogen having been converted into the form of nitric acid, it immediately combines with available bases in the soil, forming salts, all of which are very easily soluble and which are carried in solution by the soil water. In a region of much rainfall, the removal of silicate in the drainage water is very rapid. Hall³ states that silicate leached during the summer or the autumn of one year are practically all removed from the soil of the Redwooded fields before the crops of the following year have advanced sufficiently to utilize them. It was formerly customary to fertilize with ammoniac salts in autumn, but the drainage water carried on analysis took a large quantity of nitrate during the months intervening between the time of fertilizing and the opening of the growing season, so that the practice was discontinued.

In regions of less rainfall or of greater surface vegetation, the loss in this way is less, reaching a minimum in arid regions where irrigation is not practised. Under

³ Hall, A. D. The Soil, p. 176. New York, 1903.

such conditions, there is a return of nitrate to the upper and its capillary water moves upward to replace evaporated water. In fact, whenever evaporation takes place to any considerable extent there is some movement of this kind. The need for catch crops to take up and preserve nitrogen is therefore greater in a humid region than in an arid or a semiarid one. A system of cropping that allows the land to stand idle for some time or a crop that requires little water, or does water, helps to utilize all the nitrate produced, and promotes the idea of nitrites as living matter.

374. *Nitrate reduction*.—The nitrate-reducing bacteria that for studies have been found that cause the oxidation of nitrites as the result of their activities. A number of forms of bacteria that accomplish a reverse action may now be considered. The several processes involved are commonly designated by the general term denitrification, and comprise the following: 1, reduction of nitrate to nitrite and ammonia; 2, reduction of nitrite to nitrite, and of these in the nitrite nitrites.

The bacteria of organisms that possess the ability to accomplish one or more of these processes is very large; it is not, greater than the number involved in the oxidation processes; but, in spite of their numbers, possession of nitrogen in ordinary stable soils is unimportant to man, although in crops of harvested produce it may be a very serious cause of loss.

Some of the specific bacteria reported as bringing about nitrate reduction are: *A. nitratus* and *B. pasteurii*, which reduce nitrite; *B. nitratus*, *B. nitratus*, *B. nitratus*, *B. nitratus*, and many other non-nitrifying bacteria which are capable of converting nitrite into ammonia.

A. denitrificans elaps and *B. denitrificans* also reduce nitrate with the evolution of gaseous nitrogen.

375. Nitrate-utilizing organisms. — In addition to the nitrate-reducing bacteria already mentioned, there are other bacteria which also utilize nitrate; but, like higher plants, these convert the nitrogen into organic nitrogen substances. However, as they operate in the dark and cannot obtain energy from sunlight, they must have organic acids or carbohydrates as a source of energy. While these bacteria cannot be considered as nitrate reducers, they help to deplete the supply of nitrate when conditions are favorable for their development. What these conditions are is not well understood, nor can we estimate its value as to the extent of their operations.

376. Denitrification. The term denitrification was first used to include both the process of nitrate reduction and that of nitrate assimilation (see Fig. 61).

Most of the denitrifying bacteria perform their functions only under a limited amount of oxygen, while others can operate in the presence of a more liberal supply; but, in general, thorough aeration of the soil practically prevents denitrification. Some apparently require an abundant supply of dissolving capacities, and also furnish a supply of carbohydrates which favor the reaction; so that stable manure is very likely to undergo denitrification, and straw or coarse stable manure are conducive to the growth of denitrifying bacteria in the soil.

Under ordinary farm conditions, denitrification is of no significance in the soil where proper drainage and good tilage are practiced. "Warington" derived that it

¹Warington, R. Investigations of Denitrified Agricultural Soils. U. S. D. A., Office of Exp. Sta., Bul. 1, p. 16, 1882.

an arable soil is kept saturated with water to the exclusion of air, nitrites added to the soil are decomposed, with the evolution of nitrogen gas. As lack of drainage usually means permanent in early spring, when the soil is likely to be depleted of nitrites, it is not likely that such loss arises in this way unless a nitrate fertilizer has been added. Among the many difficulties arising from poor drainage, destruction of an expensive fertilizer may be a very considerable item.

The addition of a nitrate fertilizer to a well-drained soil receiving stable manure is most likely to result in a loss of value unless the dressings of manure have been extremely heavy. Hall¹ states that at Hertswood, where large quantities of sludge of solids are used every year in consecutive individual dressings of firm manure, the nitrate produces nearly as large an increase when added to the manure as when added to the unmanured plot. In other words, there appears to be no loss of nitrate by denitrification.

It is possible to work a point in connection with fertilization that may take place. Market gardeners sometimes reach this point, when they have a store of heavy manure, in addition to a nitrate fertilizer, are added to the soil. Plowing under heavy crops of grass manure may produce the same result. In either case, the best way to overcome the difficulty is to allow the organic matter to partly decompose before adding the fertilizer. The reason of the early decomposition of nitrates is caused by the denitrifying organisms becoming so prolific that their activity

¹ *17*. Nitrogen fertilizer through experiments with higher plants — it has long been recognized by farmers that

¹ Hall, A. D. *The Book of the Incomplete Experiment*, N 114-115, June 1905, 1906.

certain crops, as clover, alfalfa, peas, beans, and many others, improve the soil, making it possible to grow larger crops of cereals after these crops have been on the land. Within the past century the benefit has been traced to an increase in the nitrogen content of the soil, and the specific plants so affecting the soil were found to be, with a few exceptions, those belonging to the family of legumes. It has furthermore been demonstrated that under certain conditions these plants utilize the uncombined nitrogen of the atmosphere (see Fig. 64), and that they contain, both in the above portions and in the roots, a very high percentage of nitrogen. In consequence, the decomposition of even the roots of the plants in the soil leaves a large amount of nitrogenous matter.

59. *Behavior of bacteria in nodules.*—It has also been shown that the utilization of atmospheric nitrogen is accomplished through the aid of certain bacteria that live in nodules (tubercles) on the roots of the plants. These bacteria take free nitrogen from the air in the soil, and the host plant secures it in some form from the bottom or their products. The presence of a certain species of bacteria is necessary for the formation of tubercles. Leguminous plants grown in culture or in soil not containing the necessary bacteria do not form nodules and do not utilize atmospheric nitrogen, the result being that the crop produced is less in amount and the percentage of nitrogen in the crop is less than if nodules were formed.

The nodules are not usually a part of leguminous plants, but are evidently caused by some irritation of the root system, such as a pull is caused to develop on a root or a branch of a tree by an insect. In a culture containing the proper bacteria, the pull of a nematode on the root surface will cause a nodule to form in the course of a few

ages. The entrance of the organism is effected through a root hair which is penetrated, and it may be seen as a filament extending the entire length of the hair and into the cells of the cortex of the root, where the growth of polythenebacteria.

Even where the causative bacteria occur in culture or in the soil, a leguminous plant may not secure any atmospheric nitrogen, or perhaps only a small quantity, if there is an abundant supply of readily available oxidized nitrogen on which the plant may draw. The bacteria have the ability to utilize combined nitrogen as well as atmospheric nitrogen, and prefer to have it in the former condition. On soils rich in nitrogen, legumes may themselves add little or no nitrogen to the soil; while in perfectly inoculated soils deficient in nitrogen an important gain of nitrogen results.

While it is understood that the organism common to all leguminous plants, it is now known that the organisms from two species of legumes are not equally well adapted to the production of tubercles in each of the other species of legumes. They show greater activity on some species than on others, but do not develop so successfully on all species as on the one from which the organisms were taken. It was rather generally believed at one time that the larger any species of legume is in contact with the organism from another species, the more active this species becomes and the greater is the utilization of atmospheric nitrogen. Considerable doubt has been cast on this view in recent years, and it is now generally accepted that the bacteria of certain legumes are not equally of equalizing activity other species of legumes.

299. Transfer of nitrogen to the plant. — It has been shown by several investigators that bacteria from the

nodules of legumes are able to fix atmospheric nitrogen even when not associated with leguminous plants. These would seem to be no doubt, therefore, that the fixation of nitrogen in the tubercles of legumes is accomplished directly by this organism, not by the plant itself nor through any combination of the plant and the organism — though both of these hypotheses have been advanced. The part played by the plant is therefore to furnish the carbohydrates which are required in large quantities by all nitrogen-fixing organisms and which the legumes are able to supply in large amounts. The utilization of large quantities of carbohydrates by the nitrogen-fixing bacteria in the tubercles may also account for the small proportion of non-nitrogenous organic matter in the plants.

How the plant obtains this nitrogen after it has been moved by the bacteria is less well understood. Early in the growth of the tubercle, a mucilaginous substance is produced, which permeates the tissues of the plant in the form of long, slender threads containing the bacteria. These threads develop by branching or budding, and from what have been called Y and T forms, known as bacteroids, which are peculiar to these bacteria. The threads finally disappear, and the bacteria diffuse themselves more or less through the tissues of the root. What part the bacteroids play in the transfer of nitrogen is not known. It has been suggested that in this form the nitrogen is absorbed by the tissues of the plant. It seems quite likely that the nitrogen compounds produced within the bacteria cells are diffused through the cell wall and absorbed by the plant.

831. Soil inoculation for legumes. — Immediately following the discovery of the nitrogen-fixing bacteria, the possibility was conceived of securing a better growth of

leguminous crops on soils not having previously grown such crops successfully. Alternative experiments showed the practicability of inoculating land for a certain leguminous crop by spreading on its surface soil from a field in which the same crop is successfully growing. It is manifestly much better to apply the organisms from a certain species of legumes from a field having grown the same species, than to attempt to use organisms from another species of legumes. The fact that soil inoculation by means of soil from other fields may possibly transmit seed, weeds and fungus diseases, and also necessitates the transportation of a great bulk and weight of material, has led to numerous efforts to inoculate soil by means of pure cultures. The pure culture may also make it possible to bring to the soil bacteria of greater physiological efficiency than those already there.

The first attempts at inoculation by pure cultures were made in Germany, the efforts being made under the name of "rhizogin." Local experiments made with this material previous to the year 1910 did not show it to be very efficient; but in recent years improvements in the method of multiplying the cultures have resulted in much greater success. In "rhizogin" the medium used for growing the organisms is grain, and before use this was formerly disinfected in water; but now a solution of potassium dichromate is used in order to prevent a change of mouldy growth, which may cause phenomena and result in the destruction of the bacteria.

Within recent years a number of cultures for soil inoculation have been offered to the public. The first of these cultures appeared rather to resemble the bacteria in a dry state from the pure culture in the laboratory in the case of the cultures, who may to prepare themselves

moisture culture to be used for inoculating the soil. Careful investigation of this method showed that its weakness lay in drying the cultures on the slantest surface, which frequently resulted in the death of the organisms. Also recently, liquid cultures have been placed on the needles in this country, and these have, in the main, proved to be more successful, notably those sent out by the United States Department of Agriculture. Another very successful culture medium, now being distributed by the Department of Plant Physiology at Cornell University, is slanted soil. The process of slanting makes a presence of two or three atmospheres increases greatly the solubility of both organic and inorganic matter, and produces a uniform highly favorable to the development of the organisms isolated from the nodules of legumes.

Liquid cultures for legume inoculation have now been prepared and distributed by the United States Department of Agriculture for seven years, and during this time a record has been kept of the results so far as it has been possible to do this. These are summarized by Kellerman* as follows: average percentage of success, 70; average percentage of failure, 30. If, however, the doubtful reports are omitted with the failures, the percentage of success is reduced to 38. Kellerman states as his opinion that inoculation with pure liquid cultures is as certain a source of infection as is inoculation with soil from fields in which legumes have been successfully grown for extended periods, if the soil to be infected is one well adapted to the leguminous crop; but on soils not well suited to legumes, the use of soil from old fields is a much more satisfactory medium with which to attempt inocu-

*Edwards, R. P. The Present Status of Soil Inoculation. *Outlook*, 1 (June, 22), 26nd 35, 36th 42-43. 1922.

ing. It is only a question of time until a successful method of introducing soil from artificial cultures will be found. In the meantime, inoculation by means of isolated soil is the most practical method.

381. *Nitrogen fixation without symbiosis with higher plants.*—If a soil is allowed to stand dry, either without irrigation or its gases, it will, under favorable moisture conditions in the northern states, accumulate in one or two years appreciable amount of nitrogen and present at the beginning of the period. At the Rothamsted Experiment Station, one of the fields in voluntary plants, containing mainly of grass without legumes, gained in the course of twenty years about twenty-five pounds of nitrogen per acre annually.¹ According to Hall, the nitrogen brought down by rain would account for about five pounds in the same year, and thus, bird droppings and the like, for a little more.

382. *Nitrogen-fixing organisms.*—Direct experiment has shown that certain bacteria have the ability to utilize atmospheric nitrogen and to leave it in the soil in a certain form (see Fig. 81). An aerobic bacillus—*Clostridium pasteurianum*—was first found to produce this result. Later, a commercial culture called "azul" was placed on the market in Germany, claimed to contain *Ascaris rubeobacillus*, with which the soil was to be inoculated, and it was claimed that a large fixation of atmospheric nitrogen would result. A number of tests of this material failed to show that it caused any marked fixation of atmospheric nitrogen.

A number of other nitrogen-fixing organisms have also been discovered. These are: (1) several members

¹Hall, A. D. On the Accumulation of Fertility by Soil. *Abstracts to Jan. 1914.* *Ann. Agr. Sci.*, Vol. 1, p. 341. 1908.

of the group designated *Anaerobacter*, which are strictly bacteria, and which some investigators hold to be capable of fixing atmospheric nitrogen when grown in pure culture, while others believe them to be able to do so, at least in large amounts, only in the presence of certain other organisms; (2) members of the *Cyanobacter* group, which are large spore-bearing bacilli of variable habit; (3) *Zoeller* endobacter, which appear to be strictly mutual to or identical with the *B. radicicola* of legume nodules. The last-named has been shown to be able to fix atmospheric nitrogen even when not growing in symbiosis with legumes.

There are doubtless many other nitrogen-fixing organisms still to be discovered.

A peculiarity of these nitrogen-fixing organisms is their use of catalyptins, when they develop in the presence of nitrogen fixation. They secure non-atmospheric nitrogen when in a nitrogen-free medium. The presence of soluble lime or magnesia salts, especially calcium, is necessary for the best performance of the nitrogen-fixing function, as is also the presence of a somewhat easily soluble form of phosphate. The organisms are exceedingly sensitive to an acid condition of the soil.

332. Mixed cultures of nitrogen-fixing organisms.

Mixed cultures of the various organisms mentioned fix larger amounts of nitrogen than do the pure cultures of any one of them, while some forms are incapable of fixing nitrogen in pure cultures. Certain algae, particularly the blue-green algae, aid greatly in promoting growth and nitrogen fixation by these organisms. That they probably do so by producing catalyptins, which are used by the bacteria as a source of energy for nitrogen fixation, the bacteria furnishing the algae with nitrogenous compounds.

to what extent this relation isymbiotic is not known at present, but it seems probable that a relation may exist, similar to that between leguminous plants and the nitrogen-fixing bacteria in their nodules.

304. Nitrogen fixation and denitrification in legumes.

Nitrogen fixation and denitrification are reverse processes. The former is, for most bacteria, favored by an abundant supply of air and a moderately high temperature. Thus, at 25° C. fixation was rapid, at 37° C. it was decreased, and at 44° C. there was no fixation. Denitrification is favored by a somewhat limited supply of oxygen.

There is no reason to believe that the practical importance of nitrogen fixation without bacteria is equal, under the most favorable conditions, to that with legumes. A further knowledge of the organisms effecting fixation and of their habits will doubtless make possible a greater utilization of their power to supplement the use of legumes as a source of available nitrogen in the soil.

TREATMENT OF SOILS WITH VOLATILE AMMONIUM AND OTHER GASES

Attention was first drawn to the effects of carbon bisulfide on the soil in a paper by Girard¹ and one by Oudemans² which appeared in 1884. Girard noticed that soil treated with carbon disulfide for the purpose of controlling a potato disease of the sprout had a more productive than the

¹Girard, A. Recherches sur l'assimilation des Minérales de l'atmosphère dans le Sol des cultures de Céréales à l'Eau de Mer. *Bull. Soc. National d'Agric., France*, p. 344, 1884.

²Oudemans, *Bevoenselgassen van de landbouw*, Wageningen, 1884.

was taken each treatment. The beneficial effect of the treatment extended to the second year.

Onion found a somewhat similar condition when the soil of vineyards treated with carbon fertiliser to all phytom showed greatly increased productivity after the treatment. The effect of carbon fertiliser on the vineyard soil was to make it possible to take grapes earlier on the same land, whereas it had previously been necessary to wait the land by growing a succession of other crops at intervals of several years. It was noted, however, that immediately after treatment the plants did not grow so well as under normal conditions. Subsequent investigations of the subject then began, and as early as 1885 Pagoud¹ reported that silica carbon fertiliser is applied to vine cultivation is temporarily depressed.

Investigation of the effect of heat on soil had begun somewhat earlier, when Frank² showed in 1880 that it increases the quantities of soluble matter, both organic and inorganic, as well as causing the soil to be more productive.

The subject has been investigated by a large number of persons, and in addition to carbon fertiliser a considerable number of other volatile substances, including ether, chloroform, and others, have been found to influence the productivity of soils. The effect of heat, particularly in steam, at various temperatures from slightly above normal to more than 200° C., has also been studied, while

¹ Pagoud, M.: *Recherches expérimentales sur les Transformations que subit l'Azote dans le Sol. Annales Agronomiques*, Paris 31, pp. 475-514, 1884.

² Frank, R.: *Ueber den Einfluss welcher die Verdichtung der Bodenluft auf die Pflanzenerzeugung ausübt. Bot. d. Jähr. Ber. Chem. Physico-mathematisches Inst. Bonn 6, Seite 57-97, 1885.*

It has been found that the mere drying of soils effects important changes in their solubility and in the bacterial processes that occur in them. As the result of the investigations, certain well-established facts have been noted and in connection with certain treatments being applied to most soils.

35. **Effects of carbon dioxide not least on properties of soils.**— Volatile acidophiles usually increase the productivity of soils, although there may be at first a slight temporary retardation of plant growth. It is of course necessary to permit the acidophile to volatilize from the soil before seed is planted. For this purpose the soil is spread out in a thin layer, in which condition it is allowed to remain until the odor of the acidophile has disappeared. Thereafter this phase is repeated and continued and the seeds are planted in it.

Other characteristic effects of association with volatile acidophiles reported by different investigators are: (1) an initial decrease in the numbers of bacteria, followed by a long-continued increase; (2) a disturbance of the equilibrium of the flora, by which certain bacteria multiply more rapidly than others; (3) a slight initial increase in ammonia content, followed by a considerable increase in the rate of production of ammonia; (4) depression of the process by which ammonia is converted into nitric acid, and a very slow recovery in the activity of the bacteria measured, as a result of which ammonia accumulates in the soil; (5) an increase in the rate at which cellulose is broken down in soil; (6) destruction of protozoa.

36. **Hypotheses to account for effects of carbon dioxide and of heat.**—A number of hypotheses have been formulated by which to account for the increased plant growth and for changes induced in soils by treat-

ment with heat and volatile antiseptics. A number of these theories will be mentioned, but it should be remembered that much important work on the subject has been done by investigators who have not advanced any hypotheses.

361. Koch's theory.—Koch¹ was the first to offer any explanation. In 1899 he stated it as his opinion that carbon bisulfide has a directly stimulating action on the plants themselves. He first² found ether to have a similar action, and confirmed his experiments with carbon bisulfide. He found that soil sterilized with heat produced better crops when treated with carbon bisulfide than when not so treated, and concludes that the effect of the antiseptic, therefore, cannot be due to the effect of the antiseptic on bacteria. He also experimented with field soils, and showed that the size of the crop on treated soils is not proportional to the quantity of nitrogen contained.

The theory of Koch has been supported by Prud³ who fertilized only with an abundant supply of sodium nitrate and found that in every case in which carbon bisulfide was added the growth and yield of crop were much superior to those in the corresponding pots and control with that substance. He concludes that as there was no lack of phosphate and other nutrients favorable to plant

¹Koch, A. Untersuchungen über die Ursachen der Fäule infizierter auf Kunenerde befeuchtigter, der Luftschwebstoffentwicklung. *Arch. Dtsch. Landw. Gesell.*, 1901-02, Seite 7-34, 1899.

²Koch, A. Über die Wirkung von ätherischen Oelbälchen (Benzolöl und Fenchöl und Niphol-Phenol). *Chemik. J. Bot.*, II, Band 94, Seite 758-760, 1901-1902.

³Prud, S. E. Effect of Prud and Volcanic Acid on Plant Growth. *Vergleich. Pflanz. Anat. Rep. Sta.*, 1904, Sept. 1900-1901, pp. 145-155.

antibiotics in the soil, and to a decrease in the number of decomposing bacteria, which causes loss of available nitrogen through their action.

Heise¹ working with soils treated with carbon bisulphide, lime, and Plaster, Frank, Wiedacker, and Hummel² working with steamed soils, found that there was a large fixation of nitrogen following these treatments. They conclude that this is at least partly responsible for the poorer productivity of the soils after the treatments mentioned.

88. Russell and Hutchinson's theory.—The new comprehensive theory to be brought forward was one by Russell and Hutchinson, who account for the increased productivity of soils partially steamed, either by heat or by volatile antibiotics, as due to the use by plants of the ammonia, which, as had been shown by previous investigations, accumulated in soils so treated by reason of the stimulation given to the process of nitrification and the decrease of cellulolysis. They held, furthermore, that the stimulation of nitrification is brought about by the greatly increased numbers of bacteria in the soil following the destruction of some larger organisms, probably protozoa or allied fauna, that normally interfere with the activities of the nitrifying bacteria. Careful experiments by these investigators have shown that there is much hyperactivity of nitrogen in the combined forms of ammonia and nitrites in partially steamed

¹Weiss, R. *Das Weissen Mittelmeer* über die Schwebelichensiedlung und die Chlorschwefelung des Bodens. *Zeitsch. f. Bakt.*, II, Band 16, Seite 68-74, 261-331, 402-471, 634-651, 795-798, 4200.

²Miller, Th., Frank, L., Freilander, K., and Hummel, P. *Die Wirkung* (Dissertation des Landwirtschaftl. Instit. v. Landw. Inst. d. Rheinl.) *Verh. Bodenk.*, Band 6, Seite 215-221, 1938.

with that in untreated soils. There can be no doubt, therefore, that, at least for some higher plants, the quantity of available nitrogen is greater in the treated soils.

The relation of potassium to the nitrifying bacteria is somewhat more difficult of demonstration. Methods by the enumeration of potassium in the soil are not sufficiently well worked out to admit of an entirely satisfactory study of their relation to the nitrifying bacteria. However, Russell and Hutchinson do not hold that potassium are necessarily the limiting factor in nitrifier production in normal soils, but point that some other equivalent of comparatively large size may be responsible for this. They infer from their data not only the available nitrogen, but also the quantities of other plant nutrients, as limited by organisms destroyed by partial sterilization; otherwise increased yields of nitrate induced by partial sterilization would be confined to soils in which nitrogen is normally the limiting factor. The theory does imply, however, that phosphate is the limiting factor in all soils benefited by partial sterilization under the conditions of the experiment.¹

¹ Russell, E. J., and Hutchinson, P. F. Contribution to soil and to nitrate in production. *Proc. 3. The influence of partial sterilization.* *Ann. Agr. Sci.*, Vol. 3, pp. 205-225, 1933.

Vossell, H. J., and Hutchinson, H. D. The effect of partial sterilization of soil on the production of plant food. *Ann. Agr. Sci.*, Vol. 3, pp. 111-144, 1933.

Vossell, H. J., and Hutchinson, H. D. The effect of partial sterilization of soil on the production of plant food. *Proc. 3.*

Russell, E. J., and Hutchinson, H. D. The limitation of nitrifier numbers in normal soils and its consequences. *Ann. Agr. Sci.*, Vol. 3, pp. 145-155, 1933.

Sheldra, W. Partial sterilization of soil by volatile and non-volatile antibiotics. *Ann. Agr. Sci.*, Vol. 3, pp. 417-433, 1933.

Some typical results of investigations by Russell and Hutchinson on the effect of partial sterilization on bacteria numbers, antibiotic production, and presence of protozoa are given below:—

| | Amount of 25% solution (100 ml) used per jar | Amount of 25% solution (100 ml) used per jar | Amount of 25% solution (100 ml) used per jar | Amount of 25% solution (100 ml) used per jar |
|--------------------------------------|--|--|--|--|
| | 100 ml | 100 ml | 100 ml | 100 ml |
| Untreated soil | 11,100,000 | 10.0 | Present | Clasidia, Ascaris, etc. |
| Soil heated to 60°C. for three hours | 2,600,000 | 7.4 | Present | Clasidia, Ascaris, etc. |
| Soil heated to 90°C. for three hours | 62,000,000 | 16.7 | Trace | Clasidia, Ascaris, etc. |

330. *Gregg-Smith's theory*.—An entirely different explanation of the effect of partial sterilization on soil has been advanced by Gregg-Smith.¹ He states that when disinfectants are applied to the soil their action is a double one. They kill the less resistant bacteria, and disorder those the surface of the soil particles a very covering, so that he has given the name "apricot." The surviving bacteria, among which are the beneficial ones, are able to develop more rapidly because of the greater accessibility of the food supply which the removal of the "apricot" has exposed.

Gregg-Smith holds that heat destroys substances which

¹ Gregg-Smith, H. The Bacteriostatics and the "Apricot" of Soil. *Contrib. I. N. S.*, 11, 1922, 104-106, 1912.

in bacteria, and also certain of the less resistant bacteria, has permitted the more resistant species to multiply very rapidly owing to the absence of the bacteriostatics.

In order to ascertain whether chlorform has any effect other than the destruction of protozoa, Greg-Smith applied it to soil previously heated to 42° C., which he had found was sufficient to kill all protozoa, and then determined the number of bacteria in untreated soil, in heated soil, and in soil heated and treated with chloroform. The counts to a gram of soil were made at three, six, and ten days as follows:—

| | 3 Days | 6 Days | 10 Days | Mean |
|---|--------|------------|------------|------------|
| Untreated soil | 10 | 100,000 | 2,700,000 | 1,400,000 |
| Soil heated at 42° C. | 15 | 15,000,000 | 11,000,000 | 13,000,000 |
| Soil heated at 42° C. and treated with chloroform | 12 | 36,500,000 | 63,400,000 | 50,000,000 |

Greg-Smith concludes that as the bacteria developed more rapidly in the soil treated with chloroform than in the soil which was only heated and in which the protozoa were presumably dead, the chloroform must have exerted some beneficial effect other than the destruction of protozoa, and assumes that this is due to the removal of "spores."

Verbal or complete sterilization of soils has been pro-

¹Greg-Smith, B. Observations on the Germination of Soil Protozoa. *Proc. Linnæan Soc. New South Wales*, 1912, Vol. 17, pp. 319-320.

Gard in greenhouses for a long time, principally for the purpose of eradicating plant diseases. Its value in increasing productivity has been a consideration since this phase of the subject has been emphasized by insecticides, and the treatment of "straw-weak" soils has been shown by Russell and Golding¹ to be a practical matter. It is as a means of studying the principles of soil fertility, however, that the investigation of the subject of partial sterilization of the soil is of greatest importance.

¹Russell, B. J., and Golding, J. Investigations on "straw-weak" in soil. Part I. "Straw-weakness." *Ann. Agr. Sci.* Vol. 3, pp. 37-47. 1913.
 Russell, B. J., and Golding, J. Investigations on "straw-weak" in soil. Part 2. "Straw-weak" in glasshouse soils. *Ann. Agr. Sci.* Vol. 3, pp. 86-111. 1913.

CHAPTER XXII

THE SOIL AIR

The air of the soil is merely a continuation of the atmospheric air into the interstitial spaces of the soil, when there are not filled with water. As it is more or less held by the soil, movement does not take place so readily as it does above the surface of the ground and here the soil air is more greatly influenced by its surroundings than is atmospheric air. This leads to important differences in composition between the atmospheric air and soil air, the composition of the latter depending on a variety of conditions in which physical, chemical, and biological properties play a part.

FACTORS THAT DETERMINE VOLUME

The amount of air that soils contain varies with their porosity, and in any one soil the air content varies with certain changes to which the soil is subject from time to time. The factors that influence the volume of air in soils are: (1) texture; (2) structure; (3) organic matter; (4) moisture content.

Soil Texture.—The size of the soil particles affects the air capacity of the soil in nearly the same way as it does the pore spaces, since in dry soil they are identical. A fine-textured soil in a dry condition would therefore contain as large a volume of air as would a

coarse-textured soil, provided the particles were spherical and all of the same size. Unlike the condition actually existing in the field, the soils composed of small particles generally possess the larger amount of air space.

382. *Structure*.—The volume of air in a soil (as soil being identical with the pore space, the formation of aggregates of particles is favorable to a large air volume. The volume of air in any soil, therefore, changes from time to time; and particularly in this case of a free-grained soil, in which the changes in structure are greater than in a soil with large particles. A change in soil structure may greatly alter the volume of air contained by changing the pore space, thereby influencing the productivity. Clay is affected to the greatest extent in this way.

383. *Organic matter*.—Since organic matter is more porous than mineral particles of any size or arrangement, the effect of this constituent is always to increase the volume of air. While this is generally beneficial in a humid region, it is often very injurious in an arid region. Unless sufficient water fills on the soil to work the soil particles around the organic matter and to maintain a supply sufficient to promote decomposition, the presence of vegetable matter leaves the soil so open that the night-lay rise of moisture is interfered with, and the considerable movement of air keeps the soil dry, with the result that the portion of the soil layer mixed with soil lying above the organic matter is too dry to germinate seeds or to support plant growth.

384. *Mohr's constant*.—It is quite evident that the larger the proportion of the interstitial space filled with water, the smaller will be the quantity of air contained. This does not necessarily mean that the higher the por-

centage of water in the soil, the smaller will be the volume of air, since the amount of pore space determines both the water and the air capacity. A soil with 20 per cent particles may contain more air than one with a water content of 20 per cent, because of the tendency of moisture to move the soil particles farther apart.

In soils, in the field, the average diameter of the cross section of the pore space is the most potent factor in determining the volume of air. Small spaces are likely to hold water, while larger spaces, not retaining water against gravity, are filled with air.

In a dry soil the volume of air is increased, other things being equal, by the formation of granules, and is decreased by decomposition or compaction. The volume of air in any soil may be calculated from the following formula:—

$$\% \text{ air space} = \% \text{ pore space} - (\% H_2O) \times (\text{as in eq. 2})$$

COMPOSITION OF SOIL AIR

The air of the soil differs from that of the outside atmosphere in that it contains more water vapor, a much larger proportion of carbon dioxide, a correspondingly smaller amount of oxygen, and slightly larger quantities of other gases, including ammonia, methane, hydrogen sulphide, and the like, formed by the decomposition of organic matter.

26. Analyses of soil air.—The composition of the air of several soils, as determined by Boussingault and Gay, is quoted by Dehmann¹ in the table following:—

¹Dehmann, S. W. New College Press, p. 538. New York, 1891.

| Observations on this | Volume of the Air or Gas, in Cubic Feet or Litres | Percentage of 20 Parts of the Air or Volume | | | |
|---|---|--|-----------------------------|--------------------------------|-------|
| | | O ₂ (C.C. No.) | Hydro- gen (C.C. No.) | Water- Vapour (C.C. No.) | Other |
| Ready soil of forest | 4.816 | 14 | 0.24 | — | — |
| Loose soil of forest | 3.285 | 82 | 0.76 | 0.95 | 20.05 |
| Barren soil of forest | 3.081 | 57 | 0.37 | 0.81 | 20.02 |
| Clay soil | 30.020 | 71 | 0.38 | 0.82 | 20.05 |
| Soil of swamps had not rested for one year | 11.083 | 86 | 0.54 | 0.82 | 10.26 |
| Soil of swamps had freely moved | 11.062 | 172 | 1.54 | 1.80 | 20.05 |
| Ready soil, six days after sowing | 11.703 | 257 | 2.11 | — | — |
| Ready soil, ten days after sowing (One day of rest) | 11.750 | 7.54 | 1.24 | 0.55 | 20.05 |
| Vegetable mold exposed | 21.043 | 772 | 2.04 | 16.65 | 20.05 |

There are several factors that influence the composition of the soil air, those of greatest importance being the production and escape of carbon dioxide.

200. Sources of carbon dioxide in soil air. The presence of carbon dioxide in soil is due in small part to infiltration from the atmospheric air, there being a tendency for the carbon dioxide, which is heavier than oxygen and nitrogen, to settle out. It may also have a purely chemical origin. But in much greater measure is the carbon dioxide a product of biological processes that occur in the soil. At one time it was believed that the formation of carbon dioxide in soils was a purely chemical process of oxidation, and possibly a part of the gas is formed in that way. It has already been seen that there is a combination of gases in the marshy parts

of the soil (see p. 268), the organic portion of which is especially capable of absorbing gases. Oxygen consumed on the surface of this organic matter would, in the words of Johnson,² "spread itself in chemical action," of which carbon dioxide would be the result.

There is now no doubt, however, that biological processes are largely responsible for the occurrence of the large quantity of carbon dioxide in the soil air. There are two distinct processes involved: (1) the physiological action of bacteria by which they absorb oxygen and give off carbon dioxide, and (2) the excretion of carbon dioxide by plant roots. The extent to which carbon dioxide is produced in normal soils in these two ways has been estimated by Stickney,³ who has done much work on the subject. He concludes that the microorganisms in a mass of soil to a depth of four feet may produce between thirty-five and seventy pounds of carbon dioxide a day for two hundred days in the year, and that during the growing period the roots of oats or wheat would give off nearly as much as in turn.

367. Production of carbon dioxide as a result of respiration.—Although the formation of carbon dioxide in the soil depends on the decomposition of organic matter, it is not always proportional to the quantity of organic matter present. The rate of decomposition varies greatly, and where this is depressed, as in some soils, even in much or forest soils, the content of carbon dioxide is relatively low. A high percentage of organic matter

¹ Johnson, R. W. *How Crops Grow*, p. 384. New York: Holt.

² Johnson, J. *Ueber den Vorrath der Gase und die Bedeutung des Bodenatmosphären im Boden*. *Gewäch. f. Baule*, II, Heft 24, June 721-726, 1906.

is in itself likely to prevent a proportional increase of carbon dioxide, since the accumulation of the gas may inhibit further activity of the decomposing organisms.

Hansen¹ states that the percentage of carbon dioxide in the soil air has the following relations:—

1. The carbon dioxide increases with the depth.
2. In general the percentage of carbon dioxide rises and falls with the temperature, being higher in the warm months and lower in the cold months.
3. Changes in temperature and air pressure change the percentage of carbon dioxide.
4. In the same soil the content of carbon dioxide varies greatly from year to year.
5. An increase of moisture in the soil increases the percentage of carbon dioxide.
6. The amount of carbon dioxide varies in different parts of the soil.

The movement of carbon dioxide from the soil depends chiefly on diffusion into the outside atmosphere. The conditions governing diffusion, which will be discussed elsewhere (see 408), therefore largely determine the rate of loss of carbon dioxide from the soil.

PERCENTAGE OF THE SOIL AIR

Both oxygen and carbon dioxide, as they exist in the air of the soil, have important relations to the processes by which the soil is maintained in a habitable condition for the roots of plants. Expired of these gases, the soil would soon become sterile.

186. Oxygen.—Its all important presence in the soil is that of oxidizing, because by it the organic matter

¹Hansen, E. *Botanische Zeits.* 1915. Berlin, 1916.

that would soon succumb to the evolution of higher plant life is disposed of, and the plant-food materials are brought into a condition in which they may be absorbed by plant roots. The presence of oxygen is essential to the life of the decomposing organisms and to the complete decay of organic matter. Through this process, roots of past crops, as well as other organic matter that has been plowed under, are removed from the soil. The process of decay gives rise to products, chiefly carbon dioxide, that are not so rich in mineral matter, and hence the nitrogen and ash constituents more or less available for plant use.

Oxygen is also necessary for the germination of seeds and the growth of plant roots. These phenomena, although not involving the removal of large quantities of oxygen, are yet entirely dependent on its presence in considerable amounts.

323. Carbon dioxide.—The solvent action of carbon dioxide is its most important function in the soil. By this action it prepares for absorption by plant roots most of the mineral substances found in the soil. Although a weak acid when dissolved in water, its universal presence and continuous formation during the growing season results in a large total effect.

Carbonic acid flows from the soil more or less of all the animals required by plants. The amounts so evolved are proportionally greater than those dissolved in pore water. The constant formation of carbon dioxide by decomposition of organic matter keeps this solvent constantly in contact with the soil.

Carbon dioxide serves a useful purpose in combining with certain bases to form compounds beneficial to the soil. Particularly is this the case with sodium carbonate,

which is of the greatest benefit to the soil in maintaining a slight alkalinity very favorable to the development of many beneficial bacteria and to the maintenance of good tilth.

Stoklosa¹ has correlated the carbon dioxide production with the quantity of phosphorus fixed in the drainage water from certain soils. Some of his results are given below:—

| | Quantity of Carbon Dioxide (Cm ³ per 100 gms. of soil) | Phosphorus Fixed in Drainage Water (mgm. per 100 gms. of soil) |
|----------------------|--|--|
| Loam | 5.2 | 14 |
| Clay | 8.5 | 15 |
| Loam soil | 8.5 | 19 |
| Heavy soil | 8.6 | 59 |

Stoklosa concludes that the production of carbon dioxide is a measure of the intensity of bacterial action in the soil, and that as consequence of this activity the phosphorus is rendered available.

When carbon dioxide is combined as sodium carbonate or potassium carbonate in considerable quantity, as in certain alkali soils, a very injurious action on plant roots and on soil moisture results. On plants the carbonate acts as a direct poison (see par. 345). The effect on soil structure is to disintegrate the particles producing the separate grains or the compact arrangement (see par. 430).

¹ Stoklosa, J. Methoden zur Bestimmung der Aersoproduktion der Bakterien in Boden. *Zell. f. d. Landw. Versuchs-Anstalten*, Band 16, Seite 159-76, 1903.

MOVEMENT OF SOIL AIR

There is a constant movement of the air in the interstitial spaces of the soil and an exchange of gases between the soil atmosphere and the outside atmosphere, as well as a more general, but probably less effective, movement of the air out of or into the soil, as the controlling conditions may determine. The movement may be produced by any one or more of the following phenomena: (1) diffusion of gases; (2) movement of water; (3) changes in atmospheric pressure; (4) changes of temperature in atmosphere or in soil; (5) action produced by wind.

Diffusion of gases.—The chief difference in the composition of soil and atmosphere air gives rise to a movement of gases due to a tendency for the actual and the ideal gases to come into equilibrium. According to Buckingham¹ the interchange of atmosphere and soil air is due in large measure to diffusion.

The rate of movement of the soil air due to diffusion is dependent on the aggregate volume of the interstitial spaces, not on their average size. Thus, it is the porosity of the soil that influences most largely the diffusion of the air from it. Unsurprisingly the size of the particles is not a factor, but good till permits diffusion to take place more rapidly than does a compact, cloddy soil, as the volume of the pore space is thereby increased. Comparing the soil in any way, as by rolling or tamping, has the opposite effect.

W. Movement of water.—As water, when passed in a soil, fills certain of the interstitial spaces, it decreases the air space when it enters the soil and increases it when

¹ Buckingham, R. Contributions to the Knowledge of the Aëriation of Soils. U. S. D. A., Bur. Soils, Bul. 38, 1906.

it flows. The downward movement of soil water produces a movement of soil air by forcing it out through the drainage channel below, while at the same time a fresh supply of air is drawn in behind the wave of saturation as the water passes down from the surface. The movement thus continued extends to a depth where the soil becomes permanently saturated with water. Twenty-five per cent of the air in a soil may be driven out by a normal change in the moisture content of the soil.

495. Changes in atmospheric pressure.— Waves of high or of low atmospheric pressure, frequently involving a change of 1½ inch on the mercury gauge, come to the surface alternately every few days. The presence of a low pressure allows the soil air to expand and issue from the soil, while a high pressure following causes the outside air to enter in order to equalize the pressures. As appreciable, but not important, movement of soil air is produced in this way.

The air of the interstitial spaces is more potent than their volume in affecting soil ventilation by this and the following methods.

496. Changes of temperature in atmosphere and soil.— A movement of soil air may be induced by a change of temperature in the atmosphere or in the soil itself. Changes in atmospheric temperature act in the same way as do changes in atmospheric pressure; in fact, it is the effect of temperature on air pressure that causes the movement. Like the movement due to atmospheric pressure, it is not great; but, when the soil immediately at the surface of the ground attains a temperature of 120° F. at midday, as is the case in the Corn Belt, the movement must be appreciable.

The diurnal change in soil temperature decreases

rapidly from the surface downward, due to the steepness and slow contraction of heat (see p. 227). At the Meteorological Department Station¹ the average diurnal range for the month of August, 1911, was as follows:—

MEANST. TEMPS. IN AIR AND SOIL TRANSMISSIONS.

| | Degree Fahrenheit |
|--|-------------------|
| Air 6 feet above ground | 144 |
| Soil 1 inch below surface | 171 |
| Soil 2 inches below surface | 168 |
| Soil 6 inches below surface | 152 |
| Soil 9 inches below surface | 151 |
| Soil 12 inches below surface | 151 |
| Soil 16 inches below surface | 152 |
| Soil 20 inches below surface | 151 |

This soil contains about 15% per cent of pore space, in the upper foot of which forty per cent is normally filled with water during the summer months. This leaves 538 cubic inches of air in the upper cubic foot of soil. With an increase in temperature, the air expands 4% in volume for each degree Fahrenheit. The average summer of temperature w_s in this case, about 11 degrees Fahrenheit for the first foot. The air column we talked by each cubic foot of soil would then be

$$\frac{538 \times 11}{491} = 11.8 \text{ cubic inches}$$

As this is slightly over two per cent of the air contained in the upper foot of soil, and as the movement below that depth is negligible, the change in composition at any

¹Wheeler, U. S. Soil Temperatures at Tucson, Arizona. Mo. Agr. Exp. Sta., 1914 Ariz. Rep., pp. 85-91. 2005.

ice time is not great; but this pumping effect is kept up day after day, although less conspicuously in the cooler seasons of the year. In proportion as pore channels equalize the temperature it would prevent this type of circulation. The total effect, aided by diffusion, is to aid materially in ventilating the soil. Owing to difference of air in the interstitial spaces, the air expelled is different in composition from that intake.

434. *Stimulation produced by wind.*—The movement of wind, being almost always in gusts alternately increases and decreases the atmospheric pressure at the surface of the soil. There is a tendency, therefore, for the soil air to escape and for atmospheric air to penetrate the soil with each change in pressure. The effect presumably influences only the superficial air spaces, but it must be very frequent in its action. No measurements have been made and no definite estimate of its effect can be stated.

MEASURES FOR MEASURING THE VOLUMES AND THE MOVEMENT OF SOIL-AIR

The conditions that influence the ventilation of soils are: (1) volume and size of the interstitial spaces; (2) moisture content; (3) daily and annual range in temperature.

Although the size of the interstitial spaces does not appear to greatly influence the diffusion of gases from a soil, it has a marked effect on certain of the other processes by which air enters and leaves the soil. A sandy soil, a soil in great till, and, particularly, a soil composed of clods, permits of more rapid movement of air than does a compact soil.

While a certain movement of air through the soil is possible, and indeed necessary, for the reasons already given, a very considerable movement is impossible when there is no abundant rainfall. The effect of air movement through the soil is to remove soil moisture. In a region of light rainfall and low atmospheric humidity, this may be disastrous if the soil is not kept compact by coverd crops. On the other hand, in a humid region and in days well known to be too small a supply of oxygen for the use of crops and lower plants. We return the soil is well stirred.

4th. Tillage. — The ordinary operations of tillage greatly influence the ventilation of the soil. When a soil is plowed, the soil at the bottom of the furrow is exposed directly to the air at the surface, and, by the separation of adhering particles and aggregation of particles, air is brought into contact with particles that may previously have been completely shut off from air. It is partly because of its effect on soil ventilation that plowing is beneficial, and the necessity for its practice is greater in a humid region and on a heavy soil than in a region of light rainfall and on a light soil. The practice of leaving rows, by which the soil is sometimes left unplowed for a number of years, although in humid regions production of crops of sufficient yield to make them profitable, would fail utterly on the heavy soils of a humid region.

Subsoiling, by loosening the subsoil, increases the ventilation to a greater depth. Hauling and subsoiling reduce both the volume and the movement of air. Their essential difference is in their effect on moisture rather than on air. Harrowing and subsoiling have the opposite effect, and both increase the production of plants in the soil by promoting aeration.

695. *Mulches*.—From various, firm, and close mulchments that improve the structure of the soil, those for that reason a beneficial action on soil aeration. By their effect on the physical condition of the soil they increase its permeability, and by their action in contributing to the production of carbon dioxide they stimulate aeration.

It is chiefly through its effect in increasing the volume of air space in soils that heavy manure is injurious in light soils of neutral reaction. It may thus be injurious instead of beneficial, if used under certain conditions.

696. *Underdrainage*.—By lowering the water table, underdrainage by means of tiles removes from the soil the water from all but the small capillary spaces, and leaves free to the air the remainder of the interstitial spaces. There is also a very considerable movement of air through the drains, and a movement of air upward from the drains to the surface of the soil, which serves to invade to some extent this intervening layer. The aeration of the soil brought about by underdrainage is one of its beneficial features.

697. *Irrigation*.—The influence of irrigation on the soil is much like that of rainfall. The alternate filling and emptying of the interstitial spaces with water and air causes a very considerable change of air.

698. *Croping*.—The roots of plants left in the soil after a crop has been harvested decay and leave channels in the soil through which air penetrates. Below the furrow slice, where the soil is not stirred, and where it is usually more dense than at the surface, this affords an important cause of aeration. The absorption of carbon from the soil by roots also causes the air to penetrate in order to replace the water withdrawn.

CHAPTER XXII

COMMERCIAL FERTILIZERS

As treated in this volume, manures include all those substances with the exception of water (the function and application of which is discussed in par. 137), that are added to soils to make them more productive. There are several ways in which manures applied to soils may increase plant growth: (1) by addition of the nutrient materials utilized by plants, which is the chief function of most of the so-called commercial fertilizers; (2) by improvement of the physical condition of a soil, which usually results from the application of humus and the incorporation of organic matter; (3) by favoring the action of useful bacteria, which is one of the beneficial results of humus manure and also of lime; (4) by counteracting the effects of toxic substances—*as, for instance, the conversion of sodium carbonate into sodium hyposulphite, or the neutralization of acidity, or possibly the destruction of toxic organic substances by carbonic acid*; (5) by making the action, either an chemical process in the soil or by its influence on those bacteria that exert a favorable influence on soil fertility or by direct stimulation of the plant.

410. *Early ideas of the function of manures.*—Manures were at one time supposed to palatize the soil, and the Plowman's manure, from which the word manure comes, implies to work with the hand. This

idea probably originated through the observation that farm manure, which was the only manure in use at that time, made the soil less cloddy.

It has been argued, notably by J. J. Tull,¹ that since tillage pulverizes the soil it may be used as a substitute for manures. There are, however, excellent reasons why tillage that is influenced by manures, and good tillage alone, will not suffice to maintain a permanently *indivisible* agriculture. It is true in the United States, as it is in Europe, that a large consumption of manure goes hand in hand with a highly developed and intensive system of farming.

4th. Development of the idea of the natural function of manures. — While the use of animal excrement on cultivated soils was practised as far back as systematic agriculture can be definitely traced, the earliest record of the use of mineral salts for increasing the yield of crops was published in 1803 by Sir Thomas Ussely.² He says: "By the help of plain salt, grease, (dissolved in water, and mingled with some other fit earthy substance, that may be had in a little salt the corn into which I confessed to introduce it,) I have made the barrenest ground bring forth the richest in giving a prodigiously plentiful harvest." His dissertation does not, however, show our true conception of the reason for the increase in the crop through the use of this fertilizer. In fact, the want of any real knowledge at that time of the composition of the plant would have made this impossible.

In 1804, Thénard in Saugy³ published his chemical

¹ Tull, *Artes, Horse-Hoeing Husbandry*, London, 1733.

² Ussely, *Experiments, A Dissertation Concerning the Vegetation of Plants*, London, 1803.

³ Thénard, *Théorie de la Nutrition Chimique par la Végétation*, Paris, 1804.

attention on plants, in which he, for the first time, called attention to the significance of the ash ingredients of plants, and pointed out that without them plant life is impossible; and, further, that only the ash of the plant comes is derived from the soil.

Justus von Liebig,¹ in his writings published about the middle of the nineteenth century, explained still more strongly the importance of mineral matter in the plant and the extraction of this matter from the soil. He refuted the theory, at that time popular, that plants absorb their carbon from flowers, but he made the mistake of attaching little importance to the presence of bases in the soil. He showed the importance of potassium and phosphorus in manures, but in his later expressions he failed to appreciate the value of nitrogenous manures, holding that a sufficient amount is supplied from the atmosphere in the form of ammonia.

A true exception of this anomaly for a supply of combined nitrogen in the soil was made at that time established by Hummingbird and by Sir John Lawes, although the chemical experiments conducted by Lawes, Gilbert, and Fyfe² in 1867 were required to fully demonstrate the fact. Their care in conducting the experiments enabled us to ascertain the soil with which they are concerned, and some other factors to discover the utilization of the atmospheric nitrogen by legumes.

¹ Liebig, J. Justus von. *Principles of Agricultural Chemistry with Special Reference to the Swiss System of Manure Management*. London, 1842. Also, *Chemistry in its Application to Agriculture and Manure*. New York, 1860.

² Lawes, J. H., Gilbert, A. H., and Fyfe, R. In *the Science of the Management of Vegetation, with Special Reference to the Growth of the Grass*. London: John & Co. 1867. *Philosophical Magazine*, Vol. 1, No. 1, 1867.

Between 1890 and 1895, the John Deere began the manufacture of bone superphosphate, and about the same time Peruvian guano and nitrate of soda were being chined into Kansas. The commercial fertilizer industry thus dates from that time.

435. *Classes of manures.*—While manures are very numerous as to kind and while a certain manure may have a number of distinct functions, they may yet be roughly divided into classes. They will accordingly be treated here under the following heads: (1) commercial fertilizers; (2) soil amendments; (3) farm manures; (4) green manures.

440. *Commercial fertilizers.*—Although the commercial fertilizer industry is little more than half a century old, the sale of fertilizers in this country amounts to more than \$130,000,000 annually. Animal refuse and phosphate fertilizers are exported, while nitrate of soda and potassium salts are imported.

Of the fertilizers sold in the United States in 1901, about 55 per cent was consumed in the North Atlantic States, in an area lying within three hundred miles of the seaboard. Nearly one-half of this remainder was purchased in the Middle Atlantic and New England States. Only five per cent was purchased west of the Mississippi River.¹

Primarily the function of commercial fertilizers is to add plant nutrients to the soil, usually in a form more readily available than those already present in large quantities. While other beneficial effects may be produced by certain fertilizers, these are usually of secondary importance as compared with the addition of the plant nutrients.

¹ Statistics from *Thirtieth Census of the United States: Agriculture of the Census*, p. 473. Washington, 1902.

41. *Fertilizer constituents*.—Fertilizer, as found on the market, are usually composed of a number of ingredients. Since these are the carriers of the fertilizing material, and since it is on their composition and solubility that the value of a fertilizer depends, a knowledge of the properties of these constituents is of interest to every one who uses fertilizers and is a valuable aid in their purchase.

NUTRIENTS OBTAINED FROM NITROGEN

Nitrogen is the most expensive constituent of manures and is of great importance, since it is very likely to be deficient in soils. A commercial fertilizer may have its nitrogen in the form of soluble inorganic salt, or combined as organic material. On the form of combination depends to a certain extent the value of the nitrogen, as the soluble inorganic salts are very readily available to the plant, while the organic forms must pass through the various processes leading to nitrification before the plant can use the nitrogen as nutrient. The inorganic nitrogen fertilizers are sodium nitrate, ammonium sulfate, nitric nitrate, and nitric cyanamide.

42. *Forms in which nitrogen exists in soils*.—There are several forms in which nitrogen exists in soils. The most direct nitrogen of the soil or available the largest supply because of its diffusibility with the atmosphere is, first, its quantity in the nitrogen of organic compounds, ranging from 0.06 to 0.3 per cent in ordinary soils; and secondly, but appreciably, soluble in soil water. In upland cultivated soils the nitrogen of nitrate salts forms the next largest supply, but rarely exceeds 24 per cent of the total combined nitrogen of the soil.

is swept and insinuated into the nitrogen of ammonia, nitrates and nitrites forms a larger proportion of the soil nitrogen than does the nitrate nitrogen, but is well stored with these compounds quite in very small quantities.

445. *Form in which nitrogen is absorbed by plants.*—The utilization of atmospheric nitrogen by leguminous plants used by a few others that have nodulose-rooting roots has been established beyond question; but the extent to which this form of nitrogen may be utilized by other plants, or the *stability* of the plants that participate in its use, are subjects on which opinions differ, and which are still being investigated.

446. *The effect of nitrogen by plants.*—Bourdingault first demonstrated the importance of nitrogen for higher plants. Previous to that time ammonia had been considered the chief source of nitrogen, and at a still earlier time humus had been considered the source. Being given the weight of his influence in favor of ammonia as the supply. He was, however, of course, of the transformation of ammonia nitrogen into nitrate in the soil. Since the publication of the experiments by Boussingault and the later work on nitrification, there has been a tendency to consider nitrate nitrogen as the only available supply of nitrogen for agricultural plants. While this is an extreme view of the matter, the fact remains that all the higher plants, including the legumes, appear to be able to absorb nitrate, and this form of nitrogen has frequently proved of greater benefit to plants than other forms of nitrogen tested at the same time.

447. *Ammonia as a fertilizer.*—That the plants of average use ammonia nitrogen rather than other forms

has been demonstrated by Kolmer¹ and later by Ledy,² (in upland soils, however, it is probable that rice plants utilize nitrate nitrogen, which would indicate that some plants, at least, may adapt themselves to the use of the more abundant form of nitrogen).

Hatchem and Miller³ found that peas obtained nitrogen from ammonium salts as readily as from sodium nitrate, but that wheat plants, although able to obtain nitrogen directly from ammonium salts, grew much better in a solution containing nitrates. One feature brought out by the numerous experiments with ammonium salts is the difference between plants of various kinds in respect to their ability to absorb nitrogen in this form.

415. Utilization of humus compounds by plants. One of the early beliefs in regard to plant nutrition was that organic matter as such is directly absorbed by higher plants. This opinion was afterwards entirely replaced by the mineral theory propounded by Liebig; and still later the discovery of the nitrifying process almost disposed completely of the belief that organic matter is a food for higher plants. It is quite certain, however, that some organic nitrogenous compounds furnish suitable nutrient material for some higher plants without undergoing bacterial change.

Thibaut and Keller, in the paper just referred to, give the following list of the organic substances used in

¹ Kolmer, O. *Agronomy*, *Journal der Landwirtschaftlichen Hochschule Berlin*, 1904, 10, 13-14, 1904.

² Ledy, W. P. *The Nutrition of Plants by Bone*, *Proceedings of the Royal Society*, 1911, 10, 10-11.

³ Hatchem, H. R., and Miller, R. H. J. *The Direct Assimilation of Inorganic and Organic Forms of Nitrogen by Higher Plants*. *Journal of Soil and Water*, 1910, 10, 10-11, 1910, 10, 10-11.

experimented by various investigators, and their availability for the nutrient of higher plants:—

Basal Nutrients

Ammonium salts:

Ammoniac (H₄, CO, NH₂)

Urea CO₂/NH₂

Urea CO₂/NH₂

Berthollet acid (with sodium carbonate)



Almona (H₄, CO₂, NH₂)

Humic

Ammoniac

Ammoniac H₄, CO, NH₂

Glycine NH₂, CH₂, COOH

Ammonopropionic acid (H₄, CH₂(NH₂), COOH

Glutamic hydrochloride $\begin{array}{c} \text{NH}_2 \\ \text{C} \\ \text{NH}_2 \end{array} \text{HCl}$

Cyanuric acid CO₂/NH₂, CO₂/NH₂

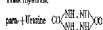
Oxamide CO₂, NH₂

Sodium aspartate CH₂(NH₂)COOH

Pyridine CH₂, COOH

DIAMMONIUM

Triorthylamine



Hexamethylenetriamine

See Diammonium

Ethyl nitrate Hydroxylamine hydrochloride
Propionitrile Methyl carbonate

THIO

Tetramethylenesulfate

This list comprises only those substances that have been used in experiments with peas. Many other substances remain to be tested, and those already tested may act differently with other plants.

One of the organic compounds isolated from soils by Koenig¹ called cyanazine, has been shown by Stinner² to be used directly by plants as a source of nitrogen, and to have produced a better growth of wheat seedlings than did an equivalent quantity of nitrogen in the form of sodium nitrate. Urethane, arginine, and creatine have also been found in soils and shown to be a direct source of nitrogen for wheat seedlings (p. 32).

There and numerous other investigations of this subject show that urea as well as amide nitrogen is assimilated by at least some agricultural plants, but to what extent most of these compounds may successfully replace the

¹Koenig, Z. G. L. The Isolation of Cyanazine from Soils. U. S. D. A., Bur. Soils, Bul. 84, pp. 11-22, 1911.

²Stinner, J. J. II. Effects of Cyanazine Plant Growth. U. S. D. A., Bur. Soils, Bul. 85, pp. 23-46, 1911.

inorganic form of nitrogen has not been definitely marked out. Certain organic nitrogenous fertilizers—as, for example, dried blood—have a high commercial value, the nitrogen in this form selling for more a pound than the nitrogen in any of the inorganic salts. Many crops, especially among garden vegetables, are most successfully grown only when supplied with organic nitrogenous material. Some nitrate nitrogen is always present under natural soil conditions, so that crops are never limited to organic nitrogen alone; and it may be that the latter form of nitrogen is most useful when it supplements the nitrate nitrogen.

445. *Indian madder*.—This now constitutes the principal source of inorganic nitrogen in commercial fertilizers. The salt exists in the crude condition in southern Chili. The crude salt is purified by crystallization, and as just in the market it contains about 36 per cent sodium nitrate, or about 14 per cent of nitrogen, 2 per cent of water, and small amounts of chloride, sulfate, and insoluble matter. The cost of nitrogen in this form is less than in sulphate or in a pound.

Because of its easy solubility, sodium nitrate acts quickly in inducing growth. For this reason it is most much by market gardeners and for other purposes when a rapid growth is desired. It is the most active form of nitrogen. A light dressing so accelerated in such crops as carrots greatly hastening growth by furnishing available nitrogen before the conditions are favorable for the process of elaboration. On small grains a somewhat useful purpose is served where the soil is not rich. Owing to the fact that nitrate is not absorbed by the soil in large quantities, it is easily lost in the draining water; for this reason it should be applied only where crops are growing on the soil, and then only in moderate quantities.

The continued and abundant use of sodium nitrate on the soil may result, through its deliquescent action, in breaking down aggregates of soil particles, thus compacting and injuring the structure. This effect is attributed to the accumulation of sodium salts, particularly the sulphate, so the sodium is not utilized by the plant to the same extent as in the nitrate.

23. Ammonium sulfate.—When coal is distilled, a portion of the nitrogen is liberated as ammonia and is collected by passing the products of distillation through water in which the ammonia is soluble, forming the commercial liquor. The ammonia thus held is distilled into sulfuric acid, with the formation of ammonium sulfate and the removal of impure gases.

Commercial ammonium sulfate contains about twenty per cent of nitrogen. It is the most concentrated form in which nitrogen can be purchased as a fertilizer, having from thirty to eighty percent more of nitrogen in a ton than sodium nitrate. It is therefore economical to handle. The effect on crops is not so rapid as that of sodium nitrate, but it is not so quickly carried from the soil by drainage water, as the commercial salts are readily absorbed by the soil. A pound of nitrogen in the form of ammonium sulfate has about the same agricultural value as the same amount in the form of nitrate if the soil on which it is used is abundantly supplied with lime; but on an acid soil ammonium sulfate has less value.

The long and extensive use of ammonium sulfate on a soil has a tendency to produce an acid condition, through the accumulations of sulfates which are not largely taken up by plants.

Ammonium sulfate, like sodium nitrate, should not be applied in surface, as the ammonia is converted into

nitrogen and leached from the soil in sufficient quantities to retard a very decided loss of nitrogen. There is no doubt to be so large a loss of nitrogen from manures, with or from nitric acid, as would naturally be expected, there is greater loss of nitrogen when the plants are not watered than when they are watered with water containing nitrogen. Hill¹ has estimated the loss of nitrogen from certain drained plots at the Rothamsted Experiment Station. This estimate is based on the concentration of the drainage from the different plots, of which there was no record of total flow, but for which the measurements of flow from the lysimeter during 60 inches of soil were taken and the total loss of nitrate was calculated on this basis. This estimate is this way the effect of several different methods of measuring are shown in the accompanying table:—

TABLE 10. LOSS OF NITROGEN FROM THE ROTHAMSTED EXPERIMENT STATION

| Treatment | 1913-14 | | 1914-15 | |
|--|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| | Drainage from the plots | Drainage from the plots | Drainage from the plots | Drainage from the plots |
| Unmanured | 1.2 | 10.2 | 0.1 | 17.1 |
| Nitric acid + 400 pounds ammoniacal nitrate | 1.0 | 11.2 | 0.7 | 17.2 |
| Nitric acid + 400 pounds ammoniacal nitrate + 100 pounds nitrate of soda | 10.5 | 11.6 | 4.5 | 16.1 |
| Nitric acid + 400 pounds ammoniacal nitrate + 100 pounds nitrate of soda | 10.1 | 11.6 | 1.0 | 16.1 |
| Nitric acid + 400 pounds ammoniacal nitrate + 100 pounds nitrate of soda + 100 pounds nitrate of soda | 10.5 | 11.6 | 3.4 | 17.1 |
| 400 pounds ammoniacal nitrate alone + 100 pounds nitrate of soda + 100 pounds nitrate of soda | 10.5 | 11.6 | 1.4 | 16.1 |
| 400 pounds ammoniacal nitrate + 100 pounds nitrate of soda | 10.5 | 11.6 | 2.7 | 16.1 |
| 400 pounds ammoniacal nitrate + 100 pounds nitrate of soda + 100 pounds nitrate of soda | 10.5 | 11.6 | 2.8 | 16.1 |

¹ Hill, J. D. The Book of the Rothamsted Experiments, p. 235, New York, 1905.

This table, in addition to confirming the statements already made in regard to the loss of nitrogen in drainage water, also shows how closely the supply of available nitrogen was used by the crops on these plots, which were generally in need of nitrogen fertilization as the plots had very little nitrogen during the growing season, while during the remainder of the year they had nearly as much as did some of the nitrogen-starved plots. The table also indicates that the loss when nitrate is used is greater than when ammonium salts are applied, as the amount of nitrogen in the 550 pounds of nitrate is nearly eight pounds to the acre more than is the 450 pounds of ammonium sulfate, which is not sufficient to account for the difference in the loss. However, half of the nitrate-treated plot received no other manure and produced only a small crop, which would naturally result in a greater loss by drainage.

425. Fertilizers containing atmospheric nitrogen. — The vast store of atmospheric nitrogen, continually replenished but very inert, will furnish an inexhaustible supply of this highly valuable fertilizing element, when it can be made available in a form in which it can be utilized in a product that will be conveniently transportable and that will retain place in the soil, be or become soluble without liberating substances toxic to plants. The importance of the nitrogen supply for agriculture may be appreciated when it is considered that nitrites are being washed off in the drainage water of all cultivated soils at the rate of (reckoned to fifty pounds) and even more, in the west annually, and that nearly as much more is removed in sewage.

The reduction of the supply of nitrogen in most soils may be accomplished within one or two generations of

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own, unless a renewal of the supply is brought about in some way. Natural processes provide for an annual restoration through the washing-down of ammonia and nitrates by rain water from the atmosphere; and through the fixation of free-atmospheric nitrogen by bacteria; but without the frequent use of leguminous crops, the supply could not be maintained. From practice of the present day require the application of nitrogen in some form of manure; and, as the need of the commercial supply of combined nitrogen is daily in sight, there is urgent need of discovering a new source. This has been done by combining calcium with atmospheric nitrogen in the form of calcium cyanamide and calcium nitride.

321. *Cyanamid*.—The trade name for calcium cyanamide is "cyanamid" and that name is therefore used in this volume. The process for the production of cyanamid consists in passing nitrogen into closed retorts containing powdered calcium carbide heated to a high temperature; the product being calcium cyanamide and free carbon:—



The free carbon remains distributed in the cyanamid and gives the fertilizer a black color. The nitrogen required for the process is obtained either by passing it over heated copper, or by the fractional distillation of liquid air.

The fertilizer, as placed on the market, is a heavy black powder or granulated material with a somewhat disagreeable odor.

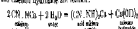
322. *Composition of cyanamid*.—Cyanamid is CaCN_2 . Cyanamid is a white mass; its chemical compound is CaCN_2 .

found in this country has about the following composition:¹—

| | Percent |
|--|---------|
| Calcium cyanamide CaCN_2 | 45.98 |
| Calcium carbonate CaCO_3 | 4.94 |
| Calcium sulfate CaS | 1.25 |
| Calcium phosphate $\text{Ca}_3(\text{PO}_4)_2$ | 0.04 |
| Calcium hydroxide Ca(OH)_2 | 26.90 |
| Free carbon C | 13.14 |
| Iron and aluminum Fe_2O_3 | 1.93 |
| Silica SiO_2 | 1.63 |
| Magnesia MgO | 0.35 |
| Combined moisture | 5.12 |
| Free moisture H_2O | 0.35 |
| Carbonaceous | 1.21 |
| | 100.00 |

According to this composition the material would contain 10 per cent of nitrogen. Taken in the form of carbonate and hydroxide would add somewhat to its value, and the residue of the calcium cyanamide, which upon decomposition is also calcium hydroxide, is likewise beneficial to the soil.

4th. Changes of calcium cyanamide by the soil.—Calcium cyanamide must be decomposed by the soil before its nitrogen becomes available to plants. There are several steps in the decomposition process by which the nitrogen finally emerges in the form of ammonia. Thus, according to Pruebe in the work just cited, the first kind of hydrolysis, by which soil calcium cyanamide and calcium hydroxide are formed:—

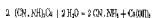


¹Pruebe, R. L. Cyanamid, p. 4. Berlin, Transvaal, 1933.

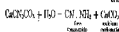
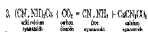
The acid calcium cyanamide quickly loses its calcium, leaving free cyanamide. Investigations differ as to the process involved in this change, but the ultimate reaction of the calcium is carbonate. The direct explanation of the process may be represented by the following reactions:—



In this reaction the carbon dioxide of the soil water is supposed to cause precipitation of the calcium.



In this case hydrolysis causes the reaction. The hydramide usually, of course, is converted into carbonate in the soil.



By this reaction calcium cyanamide carbonate is an intermediate product, but it is at once hydrolysed and free cyanamide produced.

The next step in the process is the formation of urea by hydrolysis of the free cyanamide:—



The changes up to the production of urea are independent of bacterial action. The urea is converted through bacterial action into ammonium carbonate:—



This may be converted into nitrate in the usual manner.

604. The use of cyanamid.—The changes so far described are those that proceed under favorable conditions in the soil. When conditions are not favorable—as, for example, when a soil is saturated with water or when it is acid—some more or less injurious products may be formed. For this reason cyanamid is not likely to be so satisfactory on soils of this nature as on better soils. Its very ready action is not well suited. Ordinarily its fertilizing value is not greatly below that of sodium nitrate, and is about equal to that of ammonium sulfate when not used in heavy applications.

It should be incorporated with the soil at least a week before planting, so it may injure the young plants if decomposition has not proceeded far enough to remove its noxious characteristics. As it must undergo this decomposition before its nitrogen becomes available to the young plants, there is an added reason for this precaution. It does not give so hot results as a top-dressing because it requires incorporation with the soil for its proper decomposition.

651. Calcium nitrate.—The other process for obtaining nitrogenous nitrogen is of more recent invention than that for the manufacture of calcium cyanamid but is not conducted on a commercial scale in this country; however, valuable cost experiments for developing nitrogen farms which are offered in certain facilities, factories for the manufacture of calcium nitrate will soon have to be established.

The process employs an electric arc to produce nitric

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made by the combination of atmospheric nitrogen, according to the simple equation:



It is very high power is required for this synthesis, requiring a temperature of 5000° to 3019° C., and the expense of the operation is determined almost entirely by the cost of the electricity.

The nitric oxide gas is passed through milk of lime, giving basic calcium nitrate:—



The calcium nitrate resulting from this process has a yellowish white color, and is easily soluble in water but deliquesces very rapidly in the air. This last property can be overcome by adding an excess of lime in the manufacture, thus producing a basic calcium nitrate which contains only 85 per cent of nitrogen. Another way of avoiding the difficulties involved by the deliquescent property of the nitrate is provided by the factory at Nidderke, Norway. This consists in first making the product, then grinding it fine and packing it in air-tight casks. The fertilizer thus prepared contains from 11 to 13 per cent of nitrogen.

Calcium nitrate contains its nitrogen in a form directly available to plants. It resembles sodium nitrate in its solubility, availability, and lack of absorption by the soil. It may be spread on the surface of the ground, as it acts as potassium nitrate and does not tend to form a crust, as does sodium nitrate.

The relative values of the different soluble nitrogen fertilizers vary with a great many conditions and can be

unusually judged only by a large number of tests. At present, both calcium nitrate and cyanamide are being produced at less cost per pound of nitrogen than in other plants, when laid down in the neighborhood of the factories in Europe. It seems fairly certain that, when the processes have been further improved, the result will be to greatly reduce the cost of available nitrogen.

68. *Organic nitrogen in fertilizers.*—The commercial fertilizers containing organic nitrogen include nitrocellulose guano, which contains 7 per cent of nitrogen when free from filler; blood meal, with 15 per cent of nitrogen; ester manure, with 3 per cent of nitrogen; and a number of refuse products from packing houses, among which are red dried blood and black dried blood, the former having about 15 per cent of nitrogen and the latter from 6 to 11 per cent; dried meat and head meal, with 12 to 13 per cent of nitrogen; ground fish, with 8 per cent of nitrogen; and tankage, of which the concentrated product has a nitrogen content of from 10 to 12 per cent and the crude tankage from 4 to 8 per cent; also hoof-meal and wool-wash-water waste, but these, because of their mechanical condition, are of very little value.

The waste made from seeds are primarily rich foods but are sometimes used as manures. They decompose rather slowly in the soil, owing to their high oil content, and are much more profitably fed to live stock than applied as farm manure. They contain some phosphorus and potash as well as nitrogen.

Manure consists of the excrement and carcasses of sea food. The composition of manure depends on the character of the species in which it is based. Carps form an and region contains nitrogen, phosphorus, and potassium, while that from a region where mides occur contains only phos-

phates—the nitrogen and potassium having been largely leached out. In a dry season the nitrogen tends to rise, soil surface and, in small quantities, ammonium salts. A deep plow contains more ammonia. The phosphate is present as calcium phosphate, ammonium phosphate, and the phosphates of other alkalies. A portion of the phosphate is readily soluble in water. Thus all the phosphate either is directly soluble or becomes so after interaction with the soil. The composition is extremely variable. The best Portman guano contains from 10 to 12 per cent of nitrogen, from 12 to 15 per cent of phosphoric acid, and from 3 to 4 per cent of potash.

Guano was formerly a very important fertilizing material, but the supply has become so nearly exhausted that it is relatively unimportant at the present time.

Of the starting products, dried blood is the most readily decomposed, and therefore has its nitrogen in the most available form. In fact, it produces results more quickly than any other form of organic nitrogen. It requires a condition of soil favorable to decomposition and nitrification, which prevents its exerting a strong action in early spring. It should be applied to the soil before the crop is planted. The blood dried blood contains from 2 to 4 per cent of phosphoric acid.

Dried meat contains a high percentage of nitrogen, but does not decompose so easily as dried blood, and is not so desirable a form of nitrogen. It may be fed to hogs or poultry to advantage, and the resulting manure is very high in nitrogen.

Red soil, while high in nitrogen, decomposes slowly, being less active than dried blood. It is of use in power-
ing less store of nitrogen in a depleted soil.

found fiber is an excellent form of nitrogen, and is as easily available as blood but has a lower nitrogen content.

Timothy is highly variable in composition, and the concentrated timothy, being more finely ground, nitrates more readily the decomposition necessary for the utilization of the nitrogen. Cracked timothy contains from 3 to 15 per cent of phosphoric acid, in addition to its nitrogen.

Leather meal and wood sawdust waste when valueless are in such a tough and indecomposable condition that they may remain in the soil for years without losing their structure. They are not to be recommended as manures.

429. *Availability of organic nitrogenous fertilizers.*—The forms in which nitrified nitrogen is available to most agricultural plants has already been noted to be nitric, ammoniacal salts, and certain organic compounds. Of the latter the simple nitrates, as urea, appear to be most readily taken up by plants. Decomposition is therefore a necessary process for most of these fertilizers, and their usefulness is, in general, proportional to the conditions with which suitable decomposition proceeds, or to the proportion of available compounds that they contain in their original condition. Guano, for instance, apparently, retains much nitrogen that is available without further decomposition. Bird blood quickly decomposes and contains few soluble substances, consisting of the simpler organic nitrogenous compounds, ammonia and urea. The decomposition process is a biological one, arising from the action of microorganisms that first break down the complicated organic compounds, forming simpler ones, and finally carry the nitrogen into the form of ammonia, then to nitrous acid, and at last to nitric acid.

Numerous attempts have been made to determine the relative availability of the nitrogen in various organic

population as in their composition. Another discrepancy arises from the fact that all soils do not respond to the same relative degree to any one fertilizer. Thus, Sackett¹ found that in some soils dried blood was assimilated more rapidly than was cottonseed meal, while in other soils the reverse was true; and that a similar difference obtained in soils with respect to the assimilation of alkali acid and flower meal. It would therefore appear to be impossible to make any classification in the relative availability of the nitrogen in various organic nitrogenous fertilizers. A considerable number of these experiments are, in the aggregate, needed in pointing out the probable relative availabilities of the more widely differing nitrogen-bearing substances.

FERTILIZATION FROM NON-MINE MINERAL

Phosphates are generally present in combination with lime, iron, or aluminum. Some of the phosphates contain also organic matter, in which case they gradually supply some nitrogen. Phosphates associated with organic matter decompose more quickly in the soil than do untreated mineral phosphates.

63. Bone phosphates. — Formerly bones were used directly in the raw condition, ground or unground. When treated they act as a fertilizer more quickly than when unground. Bone bones contain about 33 per cent of phosphoric acid and 4 per cent of nitrogen. The phosphorus is in the form of tricalcium phosphate ($\text{Ca}_3(\text{PO}_4)_2$).

Most of the bone now on the market is first boiled or

¹ Foulk, W. G. The Assimilating Efficiency of Certain Organic Solts. Colorado Agr. Exp. Sta., Bul. 184, pp. 5-22, 1915.

steamed. This frees it from fat and nitrogenous matter, both of which are used in other ways. Steamed bone is more valuable as a fertilizer than raw bone, because the fat in the latter retards decomposition and also because steamed bone is in a better mechanical condition. The form of the phosphoric acid is the same as in raw bone and constitutes from 28 to 33 per cent of the product, while the nitrogen is reduced to 1½ per cent.

Bone meal, which has already been spoken of as a nitrogenous fertilizer, contains from 7 to 9 per cent of phosphoric acid, largely in the form of tricalcium phosphate. All these bone phosphates are slow-acting nutrients, and should be used in a finely ground form and for the permanent benefit of the soil rather than as an immediate source of nitrogen or phosphorus.

351. *Mineral phosphates.*—There are many natural deposits of mineral phosphates in different parts of the world, some of the most important of which are in North America. The phosphorus in all these is in the form of tricalcium phosphate, but the materials associated with it vary greatly.

Apatite is found in large quantities in the provinces of Ontario and Quebec, Canada. It exists chiefly in crystalline form. The tricalcium phosphate of which it is composed is in one form associated with sodium fluoride and in the other with sodium chloride. The Canadian apatite contains about 40 per cent of phosphoric acid, being richer than that found elsewhere. Phosphorite is another name for apatite, but is chiefly applied to the impure amorphous form.

Coprolites are secondary nodules found in the chalk or other deposits in the south of England and in France. They contain from 25 to 30 per cent of phos-

phosphoric acid, the other constituents being calcium carbonate and silica.

Finally Carolina phosphate contains from 24 to 26 per cent of phosphoric acid and a very small amount of iron and alumina. As these substances interfere with the manufacture of superphosphate from rock, their presence is very undesirable—rock containing more than from 3 to 6 per cent being unsuitable for this purpose.

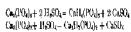
Florida phosphates exist in the form of soft phosphate, yellow phosphate, and breckle phosphate. Soft phosphate contains from 15 to 20 per cent of phosphoric acid, and because of its being more easily ground than most of these rocks it is often applied to the land without being first converted into a superphosphate. The other two kinds, yellow phosphate and breckle phosphate, are highly variable in composition, ranging from 20 to 40 per cent in phosphoric acid content. Tennessee phosphate contains from 26 to 33 per cent of phosphoric acid.

Bone slag, or, as it is also called, phosphate slag or Thomas phosphate, is a by-product in the manufacture of steel from pig-iron rich in phosphorus. The phosphorus present is usually considered to be in the form of tricalcium phosphate, $\text{Ca}_3(\text{PO}_4)_2$, or possibly a double silicate and phosphate of iron having the composition $[\text{Ca}_2\text{Si}/\text{Fe}]\text{P}_2\text{O}_7$. It contains also calcium, magnesium, aluminum, iron, manganese silica, and sulfur. Because of the presence of iron and aluminum, and because its phosphorus is more readily soluble than tricalcium phosphate, the ground slag is applied directly to the soil without treatment with acid.

The degree of acidity to which the slag is treated is supposed to be an important factor in determining its solubility in the soil. It is much more soluble in water

changed with carbon dioxide than in pure water, a property that greatly increases its value because of the fact that soil water always contains more or less of this gas. It is also readily acted upon by organic acids. For this reason it is particularly effective in a peat soil, and likewise in most soils deficient in lime. As it contains a considerable quantity of free lime it has another beneficial effect on acid soils.

482. Superphosphate fertilizers.—In order to render more readily available to plants the phosphorus contained in bone and mineral phosphates, the raw material, purified by being washed and finely ground, is treated with sulphuric acid. This results in a replacement of phosphate root by sulfate root, with the formation of monocalcium phosphate and calcium sulfate, and a smaller amount of dicalcium phosphate, according to the reactions:—



The dicalcium phosphate being in excess of the sulphuric acid used, none of it remains unchanged.

In the treatment of phosphate rock some of the sulphuric acid is consumed in acting on the impurities present, which usually consist of calcium and magnesium carbonates, iron and aluminium phosphates, and calcium chloride or fluoride, converting the bases into sulfates and forming calcium fluoride, water, hydrochloric acid, and hydrofluoric acid. The resulting superphosphate is therefore a mixture of monocalcium phosphate, dicalcium phosphate, tricalcium phosphate, calcium sulfate, and iron and aluminium sulfates.

In the superphosphates made from bone, the iron and aluminium sulfates do not exist in any considerable

quantities. However, as long as the phosphorus remains in the form of monocalcium phosphate, the value of a pound of available phosphorus in the two kinds of fertilizer is the same; but the remaining tricalcium phosphate has greater value in the bone than in the rock superphosphate.

The superphosphates made from animal bone contain about 12 per cent of available phosphoric acid and from 3 to 4 per cent of insoluble phosphoric acid. They also contain some nitrogen. Bone ash and bone black superphosphates contain practically all their phosphorus in an available form, but they contain little or no nitrogen. South Carolina rock superphosphate contains from 12 to 14 per cent of available phosphoric acid, including from 1 to 2 per cent of essential phosphoric acid. The best Florida rock superphosphates contain from 12 per cent downward of available phosphoric acid, some of which is essential. The Tennessee superphosphates contain from 14 to 16 per cent of available phosphoric acid.

Double superphosphates.—In making superphosphates a material rich in phosphorus must be used, and has often 16 per cent of tricalcium phosphate being necessary for their profitable production. The poorer materials are sometimes used in making what is known as double superphosphates. For this purpose they are treated with as much of dilute sulfuric acid as the insoluble phosphorus and the excess of sulfuric acid are separated from the mass by filtering, and are then used for making superphosphates in the ordinary phosphate rock (see below) superphosphates. The superphosphates so treated contain more than twice as much phosphorus as those made in the ordinary way.

441. *Insoluble phosphoric acid.*—A change sometimes occurs in superphosphates so standing by which some of

the phosphoric acid becomes less easily soluble, and so that even the value of the fertilizer is diminished. This change, known as *reversion*, is much more likely to occur in superphosphates made from rock than in those derived from bone. It will also vary in different samples, a well-made article usually undergoing little change even after long standing. It is supposed to be caused by the presence of unincorporated tricalcium phosphate out of iron and strontium salts.

634. *Relative availability of phosphate fertilizers.*—Superphosphates and double superphosphates contain their phosphorus in a form in which it can be taken up by the plant at once. They are therefore best applied at the time when the crop is planted, or shortly before, or they may be applied when the crop is growing. Single phosphates, on the other hand, become available only through the natural processes in the soil. They should be applied in quantity sufficient to meet the needs of the crops for a number of years.

General phosphates, although not soluble in water, is readily soluble in dilute acids. It is now generally believed that in this form an available supply of phosphorus is furnished to the plant. In a statement of 20 different analyses reported phosphorus is termed *extractable*, and this and the *water-soluble* are termed *available*.

The degree of decay to which the material is ground makes a great difference in the availability of the less soluble phosphate fertilizers, especially in the ground-sown phosphates used in ground hoes. The material should be ground fine enough to pass through a sieve having meshes at least one-fourth of an inch in diameter.

635. *Changes that occur when superphosphates is added to soils.*—When incorporated with soils superphosphate

undergoes changes, the nature of which depends more or less on the properties of the particular soil with which it is mixed. No matter how readily soluble the phosphorus may be in the fertilizer, it soon becomes insoluble in the soil, only a fractional proportion of it being absorbable in water extracts. Absorption by colloidal complexes in the case of a part of the phosphorus, in which condition it is still available to plants, especially when the colloidal matter becomes coagulated. The excess phosphorus enters into combination with the calcium of the soil, forming tricalcium phosphate and some dichalcium phosphate, and with the iron or the aluminum, forming phosphates of these metals. The latter compounds are less readily soluble than the former, and probably do not serve as a direct source of phosphorus for plants; while tricalcium phosphate, although acted upon by plant roots, is not so readily available as is the phosphorus held by the colloidal matter.

It is probable that there should be an abundant supply of calcium in a soil in which a superphosphate is added, because the phosphorus not absorbed by the colloidal matter of the soil will, under such circumstances, form more calcium phosphate than if only a small supply of lime is present, according to the law of mass action. The great loss of availability through the conversion of phosphorus into lime and aluminum phosphates may thus be mitigated.

68. *Other factors influencing the availability of tetra-calcium phosphates.*—As this is the form in which phosphorus is probably most extensively sold in the ordinary soil, and as it is a slow form of phosphorus in nature, it is a matter of some importance to know the most favorable conditions for its utilization by agricultural plants. Investigation by numerous investigators has established at least four factors that influence the availability

of this substance: (1) kind of plant grown; (2) degree of acidity of soil; (3) humus content of organic matter; (4) character of the accompanying salts.

431. **Effect of plants on the availability of tricalcium phosphate.**—It is to be expected that the various kinds of plants should not all exert an equal influence on the availability of the phosphorus of tricalcium phosphate. Probst¹ found that lupines, mustard, peas, buckwheat, and vetch responded to fertilization with raw rock phosphate in the order named, while the cereals did not respond at all. He did not include maize in his experiments, but that crop is said to respond well to difficultly soluble phosphates. It is generally considered that those plants which have a long growing season are better able to utilize tricalcium phosphate than are more rapidly growing plants. An explanation for the ability of some plants to utilize the phosphorus of difficultly soluble phosphates more successfully than do other plants has been sought in the rate of excretion of carbon dioxide by plant roots. It has already been stated (see 354) that Stokken and Frost found that the capacity of a plant to absorb phosphorus from difficultly soluble phosphates is proportional to the rate at which carbon dioxide is given off by the roots, but that the experiments of Kouskoff and Daniloff failed to confirm these results. This question is being up with the larger one involving the solvent action of plant roots, regarding which little is now known.

432. **Effect of acidity on the availability of tricalcium phosphate.**—It is recognized that raw rock phosphate is more available to the same plant in some soils than in others, and a number of persons have stated, as the result

¹ Probst, H., *Beitrag über Verzehrbare Verester mit Kalkphosphaten unter Bodenbed.* Muenchen, 1903.

of experiments, that the availability is greater in soil with than in those strongly basic. If acidity of the soil is due to the presence of free soil (free soil acidity), it is conceivable that the availability may be due to the solvent action of the soil acid on the surface of the crystalline phosphate, producing the dissoluble salt, which appears to be fairly readily available to plants. When, however, soil acidity is due to a lack of acidity (apparent acidity), the case is different. Gohrisch¹ explains this on the basis of the absorptive properties of the apparently acid soil. He regards rock phosphate, not as a chemical compound, but as a solid solution of dissoluble phosphate with lime. It is this excessive liminess of the phosphate which is responsible for its unavailability. Absorption of the excess calcium would leave the phosphate in a more readily available condition by forming the dissoluble salt, and this is brought about in an apparently acid soil.

Gohrisch experimented with a highly basic soil that did not respond to fertilization with rock phosphate. He irrigated this soil to repeated readings with distilled water charged with carbon dioxide. After such treatment, the soil gave a marked increase in crop yield rock phosphate as compared with the same soil untreated. According to Gohrisch the greater availability of the phosphate after treatment with carbonic acid was due to the removal of bases and the greater absorptive power of the soil brought about thereby. This was further corroborated by the fact that this treated soil responded to a test for insolubility while the untreated soil did not. Wilcox

¹Gohrisch, F. E. *Soils to which Rock Phosphate may be Applied with Advantage*. Jour. Agronomy (Berkeley), Vol. 21, pp. 259-269, 1931-1932. The author saw in Gohrisch in the U. S. Division for his translation.

unnecessarily sweeping all of Chabriel's explanation of the phenomenon, there can be little doubt that lack of lability is a factor in the availability of new rock phosphate in some soils.

420. *Influence of fermenting organic matter*.—There has been great difference of opinion among investigators as to the effect of fermentation of organic matter on the availability of the phosphate of tricalcium phosphate. The contention that the availability is increased probably originated with Strubbe,¹ the results of whose experiments with horse manure indicated that the availability is increased by fermentation. A large number of experiments have been conducted with new rock phosphate compared with stable manure, among which may be mentioned those by Hartwell and Perkins² and also by Steingard and Hoffman³ who in carefully conducted experiments failed to find that the availability of the new phosphate was increased by fermentation with stable manure. Opposing results have also been obtained, however, and the evidence is somewhat conflicting. Kellie,⁴ who thinks that the action of bacteria is due to the weak clay particles, explains the contradictions in the various

¹Strubbe, J., Deventer, P., and Pica, J. Über die Wirkung der Fäulnis auf die Gaselementierung. *Chem. Z. Natur.*, 11, Band 1, Seite 538-407, 544-458. 1902.

²Hartwell, R. L., and Perkins, F. R. The effect of manure on the availability of rock phosphate. *Trans. Amer. Agr. Soc.*, 1914, 1912.

³Steingard, W. B., and Hoffman, C. The Effect of the Change in Solubility and Availability of Phosphate in Fermenting Manure. *Trans. Amer. Agr. Soc.*, 1914, 1912.

⁴Kellie, E. Über die Löslichkeit der Phosphorsäure aus phosphatischem Gestein unter der Einwirkung von Bakterien und Gärung. *Ann. d. Landw. Hochs.*, 57, 864, 883. 1905-1914.

experiments in relating them to the different kinds of fermentation that the organic matter undergoes. He thinks that acid fermentation renders the phosphates more readily soluble, while fermentation that does not give rise to acids leaves it in an insoluble condition.

Connected with the biological process that results in the transformation of insoluble phosphates into soluble, there is, according to Stollman, and others, a reverse biological process resulting in the transformation of soluble phosphates into insoluble.

Whatever may be the conditions under which free rock phosphate is rendered more readily soluble or available by fermentation of organic matter, it does not appear that compounding with stable manure produces this change, at least from results of numerous experiments including those mentioned above. These have been mainly opposed to wet soil conditions.

4th. Influence of water salts.—The presence of certain salts has been found to influence the availability of difficultly soluble phosphates. The subject has been investigated by a large number of experimenters and it will be possible to summarize their results only in part and very briefly. It has been found, for instance, that calcium carbonate decreases the availability of free rock phosphate and bone-meal. Sodium nitrate reduces the availability of the tricalcium phosphates, while the strontianium salts increase their availability. Iron salts decrease availability. The influence of other salts has not been so well worked out. Thomsen¹ is the result of his extended experiments on the subject, holds that

¹ Thomsen, U. Über den Einfluss von Kalksalzen auf die Wirkung von verschiedenen Phosphaten. *Landw. Vers. Stat.*, Heft 75, Seite 357-379. 1911.

with from which plants absorb odd in larger amounts than they do when decrease availability, or at least do not collect it, while salts from which plants absorb the bases in greater quantity than the salts have a tendency to render the phosphates more available, because of the solvent action of the salt.

PRODUCTION OF POTASSIUM FERTILIZERS

The production of potassium fertilizers is largely confined to Germany, where there are extensive beds varying from 50 to 150 feet in thickness, lying under a region of country extending from the Harz Mountains to the Elbe River and known as the Stassfurt deposits. Deposits have lately been discovered in other parts of Germany.

441. Stassfurt salts.—The Stassfurt salts contain their potassium either as a chloride or as a sulfate. The chloride has the advantage of being more soluble in the soil, but its exact response to the soil is problematic. Potassium chloride in large applications has an injurious effect on certain crops, among which are tobacco, sugar beets, and potatoes. On cereals, legumes, and grasses, the chloride appears to have no injurious effect.

The mineral produced in largest quantities by the Stassfurt mines is kainit. Chemically it consists of magnesium and potassium sulfate and magnesium chloride, or of magnesium sulfate and potassium chloride. Kainit has the same effect on plants as has potassium chloride. It contains from 15 to 20 per cent of potash and from 5 to 10 per cent of sodium chloride, with some chlorinated sulfate of magnesium.

Kainit should be applied to the soil a considerable time before the crop for which it is intended is planted.

It should not be drilled in with the seed, as the action of the chlorine is direct contact with the seed, may injure its viability. Its addition to the potassium added to the soil by leach, there are also in this fertilizer magnesium and sodium. The magnesium may be dispensed with if there is much already present in the soil (see p. 418). Sodium may to some extent replace potassium in the soil naturally, and in that way may be beneficial.

Silicic acid contains its potassium bound as silicate and is soluble. It also contains sodium and magnesium chlorides. Potash constitutes about 16 per cent of the material. Owing to the presence of chlorine, it has the same effect on plants as has kainit.

The commercial form of potassium chloride generally contains about 80 per cent of potassium chloride or 50 per cent of potash. The impurities are largely sodium chloride and insoluble mineral matter. The possible injury to certain crops from the use of the chloride has already been mentioned. For crops not so affected, potassium chloride is a quickly acting and effective source of potassium, and one of the cheapest forms.

High-grade sulfate of potassium contains from 45 to 50 per cent of potash. Unlike the chloride it is not injurious to crops, but is more expensive.

There are a number of other Stassfurt salts, consisting of mixtures of potassium, sodium, and magnesium in the form of chlorides and sulfates. They are not so widely used for fertilizers as are those mentioned above.

522. **Wood ashes.**—The same time after the use of boilers because an important farm product, wood ashes constituted a large proportion of the source of supply of potassium. They also contain a considerable quantity of lime and a small amount of phosphorus. The product

known as industrial wood ashes contain from 5 to 8 per cent of potash, 8 per cent of phosphoric acid, and 30 per cent of lime. Lardered wood ashes contain about 1 per cent of potash, 1½ per cent of phosphoric acid, and from 28 to 30 per cent of lime. They contain the potassium in the form of a carbonate, which is available in its reaction and in large amount may be injurious to seeds. They are beneficial to acid soils through the action of both the potassium and calcium salts. The lime is valuable for the other effects it has on the properties of the soil. (See page 454-457.)

443. Insoluble potassium fertilizers.—Insoluble forms of potassium, existing in many rocks usually in the form of a silicate, are not regarded as having any material value. Experiments with heavy ground felspar have been conducted by a number of investigators, but have, in the main, given little encouragement for the successful use of this material. An insoluble form of potassium is not given any value in the rating of a fertilizer based on the results of its analysis.

SULFUR AND SULFATES AS FERTILIZERS

The use of these substances as a means of promoting plant growth when applied to soil has recently received considerable attention. The use of free sulfur has been investigated to some extent in France and Germany. These have been suggested: (1) those crops in which it may be beneficial to plants; (2) as a direct stimulant; (3) by its influence on the activities of microorganisms; (4) as a source of plant food, which might otherwise be deficient.

444. The use of free sulfur.—Schulze¹ applied various forms of sulfur to a soil at the rate of 25 parts to a million

¹Schulze, R. *Anteil des Schwefels an dem wasser in vegetations*. *Chem. Zentr. Acad.* 88, Paris, T. 134, pp. 359-370, 1912.

of soil. He obtained increased growth in all treated plots on which carrots, beans, celery, lettuce, sweet, dumplings, potatoes, onions, and spinach were grown, the weight of the crops on the treated soil being from 10 per cent to 45 per cent greater than those on the untreated soil. He said that had been observed before applying sulfur the effect was much less, from which he concludes that the beneficial effects were due to the influence of the sulfur on the microorganisms of the soil. There may be some question, however, whether this conclusion is justifiable. Sulfur was found by Bousinger and Duguet¹ to have no effect on the soil. Beneficial effects from the use of free sulfur have also been obtained by Denbigh² and by Bechard³ among others, while van Peckham⁴ found it to be ineffective as a fertilizer.

That free sulfur may, under some conditions, exert a beneficial influence on plant growth must undoubtedly be conceded, but how the action is brought about remains to be satisfactorily demonstrated. Free sulfur is insoluble and cannot be absorbed by plant roots. However it is readily oxidized in soil⁵ eventually producing sulfates which are in the soil and in this form may readily be taken up by plants.

¹ Bousinger, E., and Duguet, H. *Recherches de l'Action Fertilisante du soufre*. Compt. Rend. Acad. Sci. Paris, 7, 338, pp. 337-353, 1903.

² Denbigh, J. *Free Sulfur Fertilizers for Soils*. Compt. Rend. Acad. Sci. Paris, 7, 334, pp. 333-336, 1903.

³ Bechard, A. *Yamoules d'Etat de l'Action des Sulfures de l'Azote sur les Plantes*. Compt. Rend. Acad. Sci. Paris, 7, 335, pp. 334-336, 1903.

⁴ Van Peckham, H. *Ueber die Wirkung des Schwefels*. Mittheilungen der Kaiserlichen Akademie der Wissenschaften, 1906, 7, 233.

⁵ Kopp, H. H. *Free Sulfur Fertilizers for Soils*. Compt. Rend. Acad. Sci. Paris, 7, 336, pp. 335-338, 1903.

415. *Similar as sulfate*.—There is less experimental evidence regarding the effect of sulfur in the form of sulfate on plant growth than there is for the free sulfur. The fact that the losses with which the sulfate is supplied are likely to have an effect on plant growth, makes the accumulation of proof by experimentation a somewhat more difficult matter. That there may be a possible difference of sulfur in arable soils has been pointed out by several investigators, including Hart and Johnson¹ in this country. They point out that crops remove more sulfur from the soil than was shown by the early determinations of sulfur in plant ash, from which a large part of the sulfur was volatilized during the process. They then proceed to calculate the sulfur removed by a number of crops on the basis of their own methods and compare this with the percentages in similar crops.

PERCENT SULFUR REMOVED AND PROPORTION FERTILIZER
NEEDED TO THE ACRE BY AVERAGE CROPS.

| Crop and Sulfur in the Soil | Sulfur in Percent in the Soil | |
|---------------------------------------|-------------------------------|------|
| | 80 | 20 |
| Wheat (30 bu.) | 15.7 | 24.1 |
| Barley (40 bu.) | 14.5 | 20.7 |
| Oats (25 bu.) | 19.7 | 18.7 |
| Corn (30 bu.) | 23.0 | 18.0 |
| RAPE (500 lb. dry wt.) | 94.0 | 20.0 |
| Trifolium (400 lb. dry wt.) | 37.5 | 25.1 |
| Salsbery (300 lb. dry wt.) | 98.0 | 44.0 |
| Peas (200 lb. dry wt.) | 12.6 | 28.5 |
| Wheat hay (200 lb. dry wt.) | 11.2 | 12.0 |

¹Hart, H. B., and Johnson, W. H. Estimation of the loss of sulfur from the soil and its supply. Wis. Agr. Exp. Sta., Research Bul. No. 14. 1911.

They then add attention to the quantities of sulfur (oxide contained in average soils which, as shown by Hignel, are less than the quantities of phosphorus pentoxide.

| | Oxide of Sulfur to one Acre | |
|-----------------------|-----------------------------|------|
| | 1A | 1A |
| Heavy soils | 1800 | 2500 |
| Light soils | 3200 | 4500 |

It is necessary, therefore, the supply of sulfur in the soil is really depleted by cropping, the same authors made parallel determinations of sulfur in five virgin soils and in five soils of the same respective types that had been cropped for sixty years. In each type the cropped soil contained less sulfur than the virgin soil, the average for the cropped soils being 650 per cent SO_2 and for the virgin soils 1750 per cent SO_2 .

There is no doubt that the quantity of sulfur carried down by rain and snow is much less than that removed in drainage water. There can be no question therefore that most soils, and especially cultivated soils, are losing more sulfur than they receive by natural processes.

It has been customary to add to soils sources of one kind or another that contain iron or less sulfur. Among these are farm manure and other animal or bird excrement, residues of crops, animal offal, gypsum or lead plaster, superphosphates, ammonium sulfate, potassium nitrate, kiesel, lime, and the like, all of which contain considerable quantities of sulfur. It seems probable that

any system of soil management that does not include one or more of these substances would probably, in some soils at least, be improved by making provision for the application of sulfur in some form.

CATALYTIC FERTILIZERS

The term *catalytic fertilizers* has been used rather loosely to designate a class of substances that, when added to a soil, increase plant growth by apparently accelerating the processes that normally take place in soils. They do not function as fertilizers because their value does not lie in the nutrients that they possess, but they may properly be classed as soil amendments. However, substances not classed as catalysts, such as lime, have such action, and in all probability most of the fertilizers do also, so that it is difficult to draw any definite distinction and the term will doubtless be used only temporarily.

448. *Nature of catalytic action.*—The term *catalysis* is employed in a chemical sense to denote a change brought about in a compound by an agent that itself remains stable. As an example of this may be cited the fact that hydrochloric acid plays in the reaction of zinc and acid not merely into the reaction but by its presence greatly accelerating it. When an attempt is made to study these phenomena in soils, it becomes difficult, owing to the multiplicity of factors and reactions to determine whether the agent is acting in a purely catalytic manner.

449. *Catalytic action of soils.*—Most soils themselves act as catalysts in so far as they hasten the decomposition of hydrogen peroxide. Many substances, both organic and inorganic, have this property, and it is not accurate

entirely lost to the soil after the organic matter has been destroyed by ignition. It is therefore not due to an enzyme, as stated by König, Haeckelmann, and Coppersmith,¹ who first investigated the subject, nor entirely to equivalent substances in the soil. Doubtless there are several, or perhaps many, activating substances any of which have this property. It is altogether likely that other enzymes exist in soils, and that they effect various reactions that are concerned in plant production. Among these substances, as pointed out by König, Haeckelmann, and Coppersmith,¹ are manganese and iron oxides, which are well known to exert catalytic action on certain reactions. While soils naturally possess certain catalytic powers, it seems possible to still further activate some soils by proper application of so-called catalytic fertilizers.

Organic matter is doubtless concerned in the catalytic properties of soils, and the investigators just mentioned found that in the soils the catalytic action varied in direct direct relation to the humus content. Still we need to say, however, did not find this correlation is held. Both organic and inorganic substances are involved in this property of soils, but the forms in which they operate are not well understood. In the main production soils have a strong catalytic effect and very poor soils are weak in this respect, but this correlation also is not constant.

¹ König, J., Haeckelmann, J., and Coppersmith, E. *Prinzipien der Regeneration der Ackerböden*. Landw. Vers. Ber., Band 6, Seite 473-474, 1902-1906.

² König, J., Haeckelmann, J., and Coppersmith, E. *Reinigungsmittel des Humusgehalts des Bodens und der Nährstoffkonzentration*. Landw. Vers. Ber., Band 6, Seite 475-476, 1902-1906.

³ Hallen, M. A., and Hall, F. R. *Soils in Soil Chemistry*, U.S. D. A., Div. 645, Bul. 66, 1913.

44b. Substances used as catalytic fertilizers.—A large number of substances have been found to act as catalytic fertilizers. Among these are various salts of magnesium, iron, aluminum, zinc, lead, copper, nickel, cobalt, cesium, boron, cesium, lanthanum, and the like. These substances stimulate plant growth when used in small quantities, and are toxic in large amounts. In water cultures a much less quantity of any of them is required to produce an increase in plant growth than when applied to an equal volume of soil. The absorptive properties of the soil and the less ready diffusibility serve to mitigate the toxic action.

Different kinds of plants respond differently to the same concentration of any of these substances. For instance, Macnamara¹ found that cesium, copper, zinc, aluminum, and sodium either retarded the germination of bean and sunflower, the germination of maize when used in equal concentrations.

(If the various plant characters mentioned, manganese is the only one that gives promise, at the present time, of usefulness on a commercial basis, and it is the only one that will receive separate treatment in this book.)

44b. Manganese.—It seems probable that all soils contain manganese, but the quantity present in some soils is very small, often being less than 0.01 per cent; in other soils, however, more than 1 per cent is found, and Kelly² reports an Hawaiian soil containing 0.74 per

¹ Macnamara, A. Quoted with other experiments on this subject by N. E. J. Mene, in *Annual Reports on the Progress of Chemistry*, Vol. 26, pp. 229-230, 1916.

² Kelly, M. F. The influence of Manganese on the Growth of *Phaseolus*. *Ann. Indus. and Eng. Chem.*, Vol. 1, p. 335, 1909.

ent of Mn(II). Sullivan and Robinson¹ examined twenty six American soils and found the content of Mn(II) to vary from 0.01 to 0.61 per cent, the average being 0.07 per cent.

Manganese is a universal constituent not only of soils, but likewise of plants grown under natural conditions; in plants the quantities present vary much more than in soils, and range from a few tenths of one per cent to nearly one-half of the total ash. However, plants may be produced in water cultures or other media in which apparently no manganese is present and a normal growth and fructification will follow. It is evident, therefore, that any block to plant growth that may occur through the addition of manganese to the soil is not due to its function as a nutrient material in the sense in which nitrogen, potassium, and phosphorus act in that respect.

(IV) *Physiological role of manganese.*—It was the discovery by Bertrand² of the existence of manganese in the essential enzymes of plants and of its function in stimulating the oxygen-carrying power of these catalytic agents that suggested its use as a stimulating agent in crop production. In water cultures a very dilute solution of manganese salts increases plant growth, but beyond a very low concentration its effect is toxic. Plants differ widely in their response to manganese, with respect both to stimulation and to injury. A certain concentration may be stimulating to one plant, and toxic to another.

Experiments in the application of manganese salts

¹Sullivan, M. E., and Robinson, W. B. Manganese as a fertilizer. U. S. D. A., Bur. Soils, Cir. 74, 1913.

²Bertrand, O. Sur l'enzyme oxydase des Sels Manganésés et sur la Constitution Chimique des Oxygènes. *Compt. Rend. Acad. Sci. Paris*, Tome 124, pp. 1262-1265, 1897.

to soils have not afforded as satisfactory results as have the trials with water cultures. Applications of a certain salt of manganese, when applied at the same rates to different soils, have in some cases produced increased growth, have in other cases had no apparent effect, and have in still other cases proved injurious to plants. The reason for this is doubtless to be found in the inherent properties of the particular soil to which the application is made.

531. *Action of manganese as a fertilizer.*—The fact that manganese stimulates plant growth in water cultures is very good evidence that it has at least a direct action on the plant. Whether it has a further influence through reactions brought about in the soil is less certain, although it seems likely that such is the case. Thus, Skinner and Sullivan¹ conclude from some of their experiments that oxidation in some soils is increased by the application of manganese salts. It also seems probable that manganese may have some influence on the activity of the micro-organisms of the soil, but this has not been definitely demonstrated.

532. *Forms of manganese and response of soils.*—The manganese salts that have been found to be effective as fertilizers are the sulfate, the chloride, the nitrate, the carbonate, and the dioxide. Of these the first has been most generally used, and in quantities up to 50 pounds per acre it has in most cases not been toxic. On acid soils it is not supposed to exert any harmful action, and on very productive soils Skinner and Sullivan, in the experiments cited above, found it to be ineffective.

¹Skinner, J. I., and Sullivan, M. X. The action of star germs on soils. U. S. D. A., Bul. 66. 1914.

which they obtained especially benefit from its use on poor soils. They agree that since very productive soils have great resistance power the use of manure is unnecessary, but since poor soils undergo constant cultivation the stimulation that this process receives by the application of manure is productive of much good. Accordingly manure is most profitably used on poor soils and deficient in time.

CHAPTER XXV

SOIL AMENDMENTS

Chemical substances are sometimes added to soil for the purpose of increasing productivity through their influence on the physical structure of the soil, and thereby on the chemical and bacteriological properties. These substances are called soil amendments. It is true that they may also exert plant-influencing effects on the soil, but that function is of minor importance.

431. *Salts of calcium.*—Calcium, although essential to plant growth, seldom needs to be added to the soil to supply the plant directly; but because of its effect on the soil properties, its use is restricted to a great number of soils.

434. *Effect on tilth and bacterial action.*—On dry soils the effect of lime is to bring the fine particles into aggregates which are loosely connected by calcium carbonate. The effect of this structure on tilth has already been explained (p. 123). On sandy soils the carbonate of calcium serves to bind some of the particles together, making the structure somewhat firmer and increasing the water-holding power. It should be used only in small quantities on sandy soils.

There is a tendency for most subsoil soils to become acid, as has already been explained (p. 263). *Acidity* may reach a point where it becomes directly injurious to certain plants, but it becomes indirectly injurious before

fast point is reached. One way in which this occurs is by curtailing the quantity of calcium carbonate in the soil. An easily available base to combine with the organic acids affects the most favorable reaction for the decomposition processes due to bacterial action, and even the best results cannot be obtained where carbonate of lime is not present. Its action in improving soil also facilitates desirable forms of bacteriological activity by increasing the permeability of the soil for air.

4th. *Selection of standard materials*.—It has been stated that the alkalies and the alkaline earths are more or less interchangeable in certain compounds in the soil. The addition of lime may in this way liberate potassium, when otherwise it would be difficult for crops to obtain a sufficient supply from a particular soil. The substitution of bases has been discussed (par. 231) and the liberation of potassium is in accord with these phenomena. Magnesium, although rarely deficient, may also be made available in this way. The use of calcium salts may, under some soil conditions, render phosphorus more available, probably by supplying a base more soluble than lime or slaked lime, with which, in soils deficient in calcium, the phosphorus might otherwise be combined. Experiments by Thiebaut¹ in which plants were grown in washed sand containing Thiebaut's nutrient solution to which traces of Si , and tri-calcium phosphate respectively were added, both with and without calcium carbonate, showed a decreased availability of the tri-calcium phosphate due to the presence of the carbonate, but neither a reduced nor an increased availability of the other bases of phos-

¹Thiebaut, D. *Ueber das Verhalten von Kalkbestandtheilen bei der Aufnahme von Pflanzennahrung*. London: New York, 1904, Seite 257-275. 1901.

phorus arising from the presence of carbonates. Neither did the availability of free or disodium phosphate appear to be influenced by calcium carbonate.

These and several experiments by Simonowitch¹ and others tend to discredit the earlier conclusions as quoted above and set out forth by Ubbelohde² regarding the favorable influence of lime on the availability of phosphorus. However, the preceding reference is still valid for earlier experiments. The principles that underlie the effect of lime on availability of phosphorus are discussed in paragraphs 268 and 269.

66. Influence of lime on the formation of nitrates in soil.—It has already been remarked that nitrification proceeds very slowly in acid soils. A nitrite has must be present with which the nitric acid may combine, otherwise the process will be inhibited by the toxic effect of the acid on the bacteria concerned in the formation of the acid. The addition of lime is the most economical method of providing the base. This is often a matter of great moment for crops that require readily available nitrogen, and is one of the important reasons for applying lime to our soils. The fact that many plants grow better in some soils than in strongly basic ones is also an indication that such plants absorb a considerable part of their nitrogen in form either of the nitrite.

Many investigators have found that the presence of calcium carbonate promotes the nitrifying and denitrifying process. The addition of calcium carbonate to a

¹Simonowitch, W. *Einwirkung des Kalks auf die Verfügbarkeit des Phosphors bei der Düngung von Pflanzensamen mit Kalium- und Natriumphosphat*. *Lecture Notes*, Bonn (1910), 11-12.

²Ubbelohde, P. J. *Phosphate Chemistry*, p. 336, 1903.

poorly leached soil was found by Johnson and Johnson,¹ to favor the formation of nitrate up to an application of 2 per cent, which is much more than would ever be applied in practice. It must be kept in mind, however, that this limit does not apply to all soils, as the absorptive properties of the soil for time will determine the maximum application that may profitably be made. Johnson and Johnson found also that the application of magnesium carbonate in excess of 0.25 per cent inhibited the formation of nitrate. Kelly² also has recently reported that the addition of magnesium carbonate to the soils with which he experimented, resulted in a marked depression of both ammonification and nitrification, and that the addition of nitrate compounds did not increase this depressing influence.

401. Effect on toxic substances and plant diseases.—Free acids are toxic to most agricultural plants. Some plants are much more sensitive than others. Alfalfa, for example, should have a slightly alkaline medium for its best growth, and any acid is very injurious. Calcium salts, in neutralizing acidity, remove this toxic condition. A liberal application of lime is therefore a precaution against injury of this kind.

The presence of soluble calcium, with its effect on the soil, retards the development of certain plant diseases, such as the "finger and toe" disease of the tomatoes. On the other hand, it may promote some diseases, as, for example, potato rot.

¹ Johnson, E. F., and Johnson, P. E. *Soils and Fertilizer Application*. Baltimore, U. S., Vol. 52, pp. 129-130, 1910.

² Kelly, W. J. "The Effect of Calcium and Magnesium Compounds on Some Bacterial Transformations of Nitrogen in Soil." *Trans. of Calif. Poly. Tech. Sch.*, Vol. 1, No. 2, pp. 33-40, 1912.

418. The *lime-magnesia ratio*. -- The physiological balancing of magnesium by calcium was first worked out by Loew¹ and the ratio in which these two cations should exist in nutrient solutions in order to secure the best growth of certain agricultural plants has been very satisfactorily demonstrated by the experiments of many investigators. The optimum ratio varies with different kinds of plants, and in general the calcium must exceed the magnesium in amount, but there is a limit beyond which it should not be present. If calcium alone is present, it acts as a toxic agent on the plant, and magnesium acts in a similar way. It is only when the ratio between these cations falls within certain limits that they exert no toxic action. This ratio varies between one part of calcium oxide to one part of magnesium oxide, and seven parts of calcium oxide to one part of magnesium oxide.

In the soil the relations of calcium and magnesium to plant growth are not so simple. It is impossible to determine the actual or the relative quantities of these cations that are available for absorption by the plant. This is mainly because the absorptive properties of soils, by which they remove the bases from solution and hold them in a somewhat difficultly soluble form. The ratio of calcium to magnesium is not likely to disturb crop yields in soils unless the quantity of magnesium present happens to be very large. Cole and Agnew² have found extremely fertile soils having ratios as high

¹ Loew, O. The Physiological Role of the Mineral Nutrients of Plants. U. S. D. A. Bur. Plant Indus., Bul. 1, p. 52, 1906.

² Cole, F. P., and Agnew, C. D. The Significance of the Lime-Magnesia Ratio in Soil Analysis. *Trans. Amer. Soc. Agr. Chem.*, Vol. 1, pp. 37-58, 1911.

as 100 CaO to 1 MgO by weight. On the other hand, coarse applications of magnesite magnetics have been found to be injurious on some soils. Even on a very heavy clay soil, at Cornell University, an application of 1000 pounds to the acre of magnesite seriously decreased the yields of sorghum and oats. The soil originally received about equal parts of calcium and magnesium.

49. Forms of calcium.—Calcium is used on the soil in the form of calcium oxide, or quicklime (CaO), water-soluble lime (Ca(OH)₂), air-soluble lime (CaCO₃), ground limestone, marl (also a carbonate), and calcium sulfate, or gypsum (CaSO₄ · 2H₂O). The application of any of these is usually called liming the soil, although gypsum does not serve exactly the same purpose as do the other forms. Owing to differences in the molecular weights of these compounds of calcium, it requires more of some forms than of others to furnish the same amount of calcium. Approximately equivalent quantities of some of the common forms when fairly pure are:—

Quicklime 55 pounds
Water-soluble lime 26 pounds
Air-soluble lime, marl, and ground limestone 100 pounds

Quicklime, and the hydrate, when added to the soil, eventually assume some of the more insoluble forms of carbonate so much as the carbonate, over time, present in the soil. It is always desirable to have present in the soil at least a small amount of calcium carbonate.

50. Carbonates.—Quicklime and water-soluble lime have a markedly alkaline reaction, and hence exert a quick, very active action that may exist in the soil. They act quickly also in liberating plant-food, particularly

nitrogen. Some soils respond more rapidly to quicklime or water-slaked lime than to carbonate of lime, especially when the soil-water is in the form of acid or ground limestone; these substances never being in such a finely divided condition as is caustic lime. The use of the caustic form of lime has been said to result in the loss of nitrogen by the too rapid decomposition of organic compounds.

On close the granulating effect of caustic lime is more marked than that of the carbonate, and for this reason the former has a distinct advantage for use on heavy clay. For the same reason an occasional moderate dressing is better than a heavy dressing given less frequently.

861. *Caustic lime*.—Air-slaked lime has the advantage of being in a finely divided condition, and does not produce the injurious action on organic matter that is sometimes attributed to caustic lime. Its effect on the granulation of clay soils is probably less pronounced than that of caustic lime.

Mast (p. 27) differs from air-slaked lime principally in its property of being in a less finely pulverized condition. It acts less quickly than does caustic lime. Owing to the fact that mast depends either greatly in the composition of their products, it is well to know the quality of the material before buying it. The carbonate of lime in mast may vary from 5 or 10 to 80 or 95 per cent in different samples.

Ground limestone has been used extensively in recent years. It is very important that it be finely ground, as on the determination of the material much of its efficiency depends. However, it is doubtful whether there is any advantage in making it finer than is required to pass through a sieve with 50 meshes to the inch.

gle. Relative effectiveness of manure, hay, and straw — In order to test the value of ground livestock and other forms of calcium carbonate, experiments in plots of two treatment with manure time have been conducted at some of the experimental stations. Reports of some of the Pennsylvania Experimental Station¹ in which plots treated with slaked lime at the rate of 100 tons per acre once in four years were compared with plots treated with ground limestone at the rate of two tons to the acre every two years, show that at the end of twenty years, in every case, the total yields were greater on the plots receiving ground limestone. After the twentieth year these plots had been continued for sixteen years, a determination of nitrogen showed the upper nine inches of soil on the limestone treated plots to contain 2501 pounds of nitrogen to the acre, and the slaked-lime plots to contain 2594 pounds. It may be inferred from these figures that the slaked lime caused a slightly greater destruction of upper matter than did the limestone.

Autumn² also conducted experiments for sixteen years with outside lime practiced by burning both straw and barley, soil the carbonate of lime is gotten rid of and not used. The average crops of rye, wheat, and hay were all larger on the plots treated with carbonate of lime.

While these experiments show, at first glance, results

¹ Walker, H. L., and Hay, E. B. General Soilwork Experiments. Pennsylvania State College, Sept. 1919, Part 2, pp. 124-131. Also, Ward, C. V. Soil Fertility. Pennsylvania Agr. Exp. Sta., Bul. 93, 1918.

² Anderson, H. J. Lime Sources and Relation to Soil Acidity. Maryland Agr. Experiment Sta. Bul. 93, pp. 123-129, 1918. Also, *Investigations on the Liming of Soils*. Maryland Agr. Exp. Sta., Bul. 110, pp. 10-21, 1923.

rather favorable to the use of carbonates of lime, a careful analysis of them by Wheeler¹ raises some doubts as to the legitimacy of this interpretation. He points out, for instance, that in the Pennsylvania experiments certain quantities of lime were used, and that no farm manure or commercial fertilizers were applied to the plots between which comparisons were made.

There is, undoubtedly, a paucity of definite and conclusive data that may be applied to the solution of the question as to the relative values of these different kinds of lime for use as soil amendments, but some information has accumulated through experience and practice that may be taken as a fairly safe guide in their use. It is well known, for instance, that burned lime has a more permanent effect on soil granulation than lime the reverse, and may therefore be expected to be more beneficial to heavy clay soils. On the other hand, burned lime is not so desirable a form to apply to very sandy soils, especially when they are likely to be dry, as there is danger that organic matter will be destroyed.

4th. *Bulbous of calcium.*—Gypsum, in which free calcium sulfate is usually applied to soil, has been used for many years and was a popular soil amendment in this country before the various commercial fertilizers were used to any great extent. It frequently was by the name of *land plaster*, and, as it was rather widely distributed in nature and not difficult to obtain, it was ground and largely used in many localities throughout the eastern states. Its popularity has waned in recent

¹Wheeler, H. A. In the *Recommendations that Only Good Fertilizers Should be Used for Agricultural Purposes*, a Book and Manual, Ohio Agricultural Experiment Station, Columbus, Oct. 4, 1912.

years, and its effectiveness has apparently decreased as the soils on which it was used have been deeper under cultivation. Possibly this is due to the tendency of these soils to become more acid, which has caused the gypsum to be less effective in liberating potassium—a property with which it has generally been credited. At present gypsum is not very generally used in soils. It must be remembered, however, that superphosphates always contain a considerable proportion of this material, and it may add appreciably to the beneficial effects of that fertilizer.

Acids from its action in liberating potassium—the actual extent of which has never been very clearly demonstrated, gypsum seems to supply sulfur to the soil. The sulfur, while it may be needed in some soils, has the disadvantage of being present as an acid, and if the acid is added in larger quantity than is consumed by plants, there is a resulting loss of basic material in the drainage water and a tendency for the soil to become more acid.

The action of gypsum in improving till is less marked than that of manure, lime or of the carbonates. A *large* source of nitrogen it is of no account, as, if applied in such quantities as those in which the other forms are used, the sulfate would be very injurious. Ordinarily it is applied at the rate of only a few hundred pounds to the acre at the most. On the whole, gypsum is not an adequate substitute for, nor so desirable a form of, carbon as the stable fertilizers, or the carbonates.

Soil. Common salt.—Sodium chloride has a marked effect on some soils, but always its effectiveness has to be well understood. The addition of sodium and of chlorine as plant constituents is clearly not the reason, as these substances are always present in soils in available form for the extent of their requirements.

The effect of sodium chloride on day-blooming soils is to liberate certain plant nutrients, among which are calcium, magnesium, potassium, and phosphorus. The action, although limited in amount, is probably, in many cases at least, partly responsible for the beneficial action of common salt.

The structure of the soil is improved by the application of sodium chloride, just as it is by lime, although usually not to the same extent.

Another effect of salt is to measure and distribute soil moisture. Its conserving action is probably due to an increase in the density of the soil-water solution, thus retarding transpiration. The film movement of water is likewise increased by the presence of salt in the solution, and in this way the upward movement of bottom water is facilitated and the supply within reach of the roots maintained in time of drought.

It has been seen that sodium is not one of the substances essential to the growth of plants. But that sodium may be substitutable, in part, for the potassium absorbed by agricultural plants in their normal growth, has been shown in this country by the experiments of Whipple and Adams;¹ and the more ready availability of the sodium applied as a chloride than of the potassium in its natural condition in some soils probably accounts in part for the beneficial effects of this salt.

It is not all salts, however, that are benefited by salt, its usefulness not being of such wide application as that of lime. Certain crops, as previously mentioned, are injured by the presence of chloride.

¹Whipple, D. J., and Adams, C. E. Concerning the Agricultural Value of Sodium Salt. Rhode Island Agr. Exp. Sta. Bul. No. 1106.

48. **Muck**—The effect of muck (see 72) is to change the structure of soil, making a heavy clay and lighter and more porous, and binding together the particles of a sandy soil. But muck of soils, but partly, only the sandy type, have a greater water-binding capacity after treatment with muck, owing to the great absorptive power which amounts to 70 per cent or more of its own weight. It is to the extent of organic matter that the physical effects of muck are due.

Muck contains 1 to 2 per cent of organic nitrogen, calculated to dry matter, which does not readily undergo *mineralization*. The addition of farm manure (which increases fertility) and of lime serves to hasten *mineralization*. Its use as an absorbent in the stable for it will be one of the best.

Very large applications of muck are necessary when it is used to improve the structure of the soil. From 15 to 20 tons per acre are frequently applied.

Muck has been used successfully as a means of *soil sterilization*, for this is somewhat analogous to the use of *sterilization* in the case of *soil sterilization*, which prevents the growth of *soil sterilization* in the case of *soil sterilization*. At the rate of 10 tons per acre it has served as a highly effective medium for *sterilization* of the soil.

Muck is also used as a *filler* in certain commercial fertilizers.

¹ Jones, T. J., and Howell, J. J. Some Experiments in Top-dressing Vineyards and Orchards. *Chemical News*, Apr. 25, 1901, Vol. 20, p. 201.

CHAPTER XXV

FERTILIZER PRACTICE

The purchase and use of commercial fertilizers in an economical way requires not only specific technical knowledge of the various materials, as already set forth, but also a certain amount of general knowledge both practical and theoretical. There are at present so many fertilizing materials on the market under various trade names, that the question as to the best one to buy for a certain crop growing under definite soil and climatic conditions becomes a difficult one. The greater the general knowledge, therefore, that a person possesses as to the effects of the different elements on plant growth, as to fertilizer inspection and control, as to methods of buying, as to house mixing, as to methods and time of application, and as to mixtures for special crops, the better he is able to select fertilizers that will result in financial gain. That a fertilizer shall be profitable is the ultimate desideratum. Moreover, as all fertilizers exert, either directly or indirectly, a residual effect, the problem necessarily broadens into a study of the systems of applying fertilizers to a series of crops or to a rotation, rather than a study of the effects of one particular fertilizer application on one particular crop.

Note.—For discussion of fertilizer practices see *Handbook*, J. R. 846 *Fertility and Fertilizers*, Chapters 13-17. *Reader, Fertilization*, 1915. Also, Van Slyke, L. L., *Fertilizers and Crops*, Chapters 19-25, and 29-35. New York, 1912. Also, Page, G. S., *Principles of Agricultural Chemistry*, Chapter 35. *Reader, Fertilization*, 1915.

626. Effects of nitrogen on plant growth.¹—(1) The close primary elements of a fertilizer, nitrogen² seems to have the quickest and most pronounced effect, not only when present in excess of the other constituents, but also when moderately used. It tends primarily to encourage aboveground vegetative growth, and to impart to the leaves a deep green color, a lack of which is usually due to insufficient nitrogen. It tends to enable to increase the plumpness of the grain, and with all plants it is a regulator in that it prevents to a certain extent the retention of potash and phosphate salt. Its application tends to produce succulence, a quality particularly desirable in certain crops. In its present effects it is very similar to causture, especially when supplied in excessive quantities.

The peculiarity of nitrogen lies not only in its absolute necessity for plant growth, its stimulation of the vegetative parts, and its close relationship to the general tone and vigor of the crop, but also in the fact that it was not one of the original elements of the world's crust. During the formation of the soil it slowly and gradually became present, brought down by rain and fixed ultimately in the soil itself mostly through the agency of bacterial action. Now now it exists largely locked up in complex nitro-organic compounds of the humus and the less changed aquatic matter, and becomes slowly available to plants

¹ Discussion of the effects of the various elements on plants may be found as follows: Russell, R. J., *Art. Cultivation and Plant Growth*, Chapter II, pp. 12-16; London, 1912. Also, Galt, A. B., *Fertilizers and Manures*, Chapters III, V, and VI. New York, 1914.

² "The abundance of nitrogen in nature is very high," see Just, T. F., *The Importance of Nitrogen in the Growth of Plants*. Cornell Univ. Agr. Exp. Sta., Bul. 567. 1917.

largely through bacterial activity. It may be stated with certainty that one of the possible limiting factors to crop growth is a lack of water-soluble nitrogen at critical periods in amounts necessary for normal crop development. Since soluble nitrogen may be very readily lost from the soil by leaching, the problem of proper plant nutrition becomes a serious one. Not only must the farmer be able to *supplement* his solution in fertilizers, *or* to obtain the highest efficiency, but he must understand the control and management of the natural feeding *as well*. The emphasis placed on all phases of the nitrogen problem serves to reveal its great importance in fertility practices.

Because of the immediately visible effect from the application of soluble nitrogen, the average farmer is prone to attribute too much importance to its influence in proper crop development. This attitude is unfortunate, since nitrogen is the highest-priced constituent of ordinary fertilizers. However, of the three primary elements it is the only one which added in excess will result in harmful after effects on the crop. Its general influence, besides its functions in the catabolic and synthetic processes of plant development, may be listed briefly as follows:

1. Nitrogen tends to increase the growth of the above-ground parts.
2. It delays maturity by encouraging vegetative growth. This alteration exchanges the crop to fruit, *or* may cause trees to winter badly.
3. It increases the ratio of straw to grain in cereals, and the ratio of leaves to underground parts in root crops.

4. *It weakens the stem and causes lodging in grain.* This is due to an extreme lengthening of the internodes, and as the leaf fills the stem is no longer able to support the increased weight.
5. *It leaves pithy.* This is especially noticeable in certain grains and fruits, as barley and peaches. The shipping qualities of fruit and vegetables are also impaired.
6. *It increases the percentage of nitrogen in the crop, particularly in the straw of cereals and in timothy hay.*
7. *Adverse reaction to disease.* This is probably due to a change in the physiological resistance to disease within the plant, and also to a thinning of the cell wall, allowing a more ready infection from without.

While certain plants, as the grasses, lettuce, radishes, and the like, depend for their sustenance on plenty of nitrogen, for the average crop it is generally better to limit the amount of nitrogen so that growth may be normal. This results in a better utilization of the nitrogen and is a marked reduction of the fertilizer cost for a unit of crop growth. This is a vital factor in all fertilizer practice, and shows immediately whether fertilization for a unit of economic harvest.

447. *Effects of phosphorus on plant growth.*—It is difficult to determine exactly the function of phosphoric acid in the economy of even the simplest plants. Further cell division and the formation of fat and albumen goes to a sufficient extent without it. Starch may be produced when it is lacking, but will not change to sugar. In grain does not form without its presence, it very probably is concerned in the production of malic acid

materials. Its close relationship to cell division may account for its presence in seeds. Its general effects on plant growth may be listed as follows:

1. *Phosphorus hastens maturity* by its effect on rate of ripening. This makes phosphorus especially valuable in wet years, and in cold climates where the season is short.
2. *It increases root development*, especially of lateral and fibrous roots. This makes it valuable with such soils as do not encourage root extension and to such crops as naturally have a restricted root development. Phosphorus is therefore valuable in fall-sown crops, in years of drought, and for forming an oil hard.
3. *It decreases the ratio of straw to grain* by hastening the filling of the grain and by promoting maturity.
4. *It strengthens the stems*, due to its balancing effect on the nitrogen.
5. *It improves the quality of the crop.* This has been recognized in the handling of pastures in England and France. The effect on vegetables is also marked.
6. *It increases percentage of phosphorus in the crop.* With cereals this is particularly noticeable in the straw.
7. *It increases resistance to disease*, also probably to insect and soil development.

Excessive phosphorus ordinarily has no bad effect, as it does not stimulate any part excessively as does nitrogen, nor does it lead to a development which is detrimental. Its lack is not quickly apparent, as in the case

of nitrogen, and so a temporary phosphorus starvation may occur without any suspicion thereof being complained by the farmer.

One of the most important phases to be noted from this comparison of the effects of nitrogen and phosphorus is the balancing power of the latter on the undesirable influence generated by the presence of an undue quantity of the former. This is a vital factor in fertilizer practice, and even normal fertilizer stimulation always results in the most economic gain. Such a normal balance is obtained only when the plant function of the several fertilizer constituents are in proper accord.

528. Effects of potash on plant growth. The effects of potash are more localized than those of nitrogen and phosphorus. Potash is essential in starch formation, either in photosynthesis or in translocation, and is a necessary component of chlorophyll. It is important in grain formation, giving plump, heavy kernels. In general it tends to impart taste and vigor to a plant. In increasing resistance to disease it tends to counteract the ill effects of too much nitrogen, which in developing tendancy it works against the ripening influence of phosphoric acid. In a general way it exerts a balancing effect on both nitrogen and phosphoric fertilizer materials, but consequently its necessity is a mixed fertilizer, especially if the needs of the soil is lacking or unsuitable. As with phosphorus, it may be present in large quantities in the soil and yet exert no harmful effect on the crop.

529. Law of the minimum.—In connection with the obvious importance of utilizing, for any particular soil and crop, a fertilizer well balanced as to the three primary elements, two queries naturally arise. These are:

(1) What are the right proportions of nitrogen, phosphorus, and potash to apply under given conditions?
 (2) What would be the effect if any one of these should not be present in such a quantity as to make it equal in function to the others? The first query cannot be disposed of until the question of fertilizer mixtures has been considered. The second, however, is not affected by so many factors, and is more closely a question of the function of the elements concerned.

Any element that enters in relatively small amounts is compared with the other important constituents chiefly because the controlling factor in crop development. Any reduction or increase in this element will cause a corresponding reduction or increase in the crop yield. This element, then, is said to be "in the balance." In fertilizer practice, ideal conditions would exist if no overabundance functioned as a decided hindrance and the active influences of each single element were fully utilized. In other words, the fertilizer would be balanced as to its relationship to normal plant growth. That such a condition is more or less ideal and theoretical is obvious; from the fact that the various fertilizers carries undesirable some or less marked changes after being applied to the soil. The composition of the soil itself is also a disturbing factor. Nevertheless, the nearer an approach can be made to such conditions, the greater will be the economy of fertilizer practice.

Numerous persons have investigated the question as to what effect an increase of no channel in the nutrient may have on crop yield, and various ideas have been advanced thereon. The idea of a definite law governing the increase of plant growth according as the channel in the substance is increased, was first suggested by

light. Wagner¹ later stated definitely that up to a certain point the increase yield was proportional to the increase in the application. This, however, evidently cannot apply every year in every field, since it is a matter of rotation observation that increased crop yield becomes lower as the lacking element is supplied. Recently Mitscherlich² has formulated a law³ which is a logarithm rather than a direct function of the increase in the element occupying the position of the minimum. Mitscherlich's law may be stated concisely as follows: the increased growth produced by a unit increase of the element in the minimum is proportional to the decrease from the maximum. The following curve (see Fig. 85) constructed from data obtained by Mitscherlich⁴ shows the trend of the increased growth curve as generated by increased application of an element in the minimum, other factors being of course, under control. This curve, translated by Mitscherlich to approximate a theoretical curve of a definite mathematical formula.

¹Wagner, H. Beiträge zur Düngekunde. Landw. Jahr., Band 15, Seite 491 ff., 1898.

²Mitscherlich, A. E. Über Gesetz des Maximum und der Grenze des Abnehmens des Wachstums. Landw. Jahr., Band 21, Seite 527-553, 1906.

³Also, Vm Beiträge zur Entwicklung der Anwendung der 18. Jahresversammlung Vörschläge über die Pflanzen. Landw. Jahr., Band 21, Seite 123-125, 1906.

⁴ $y = a(1 - e^{-bx})$. Integrating, $\log y = \log a - bx$.

$\frac{dy}{dx} = a(-e^{-bx})$. Integrating, $\log y = \log a - bx$.

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FIG. 45.—Curve showing the normal growth of salt under the influence of constantly increasing amounts of phosphate, thus the increasing of the moisture.

The formula as proposed by Mitscherlich has been questioned by several investigators,* who have shown that a number of conditions, such as light, heat, and

*Hofmeier, Th., *Monat. H.*, and Thiers, M., *Wissenschaften und Landwirtschaft* von (Pflanzen von Meissner). *Landw. Ver. Zeit.*, Band 79, Seite 211-222, 1902.
Also, Mitscherlich, P., *Spektroskopie und ihre Beziehungen zu den Pflanzen*.

minerals, tend to disturb the equilibrium of such a law. The fact that crop yield is the summation of so many varying factors seems to argue in favor of no hard and fast rule regarding the increased growth due to the added nutrients of an element in the minimum. It is enough, in the practical utilization of fertilizers, to remember that this curve in general approximates the one already cited, and that in order to obtain the best results from a complete fertilizer a mixture should be used that is approximately balanced so far as the effects of the elements are concerned, the crop as well as the chemical constitution of the soil being considered.

5th. Fertilizer brands.—In an attempt to meet the demands for well-balanced fertilizers suited to various crops and soils, manufacturers have placed on the market numerous brands of materials combining equally at least two of the important elements and nearly always the three; the former being designated as incomplete fertilizers, while the latter are spoken of as complete fertilizers. These various brands usually have some catchy name, such as "The United Corn Special," "Farmers' Favorite and Grain Fertilizer," "The Golden Harvest," or "The Virginia State Sun Crop Fertilizer." Such a name frequently implies the usefulness of the material for some particular crop, but oftentimes it has no relation either to crop or to soil. Obviously the name should be ignored in the purchase of fertilizers.

A brand of fertilizer is usually made up of a number of materials containing the important ingredients. These materials, already described, are often synthetic. The making-up of a commercial fertilizer consists, then, in

merely mixing the various series together so that the required percentages of nitrogen, potash, and phosphate acid are obtained, care being taken that no detrimental reaction shall occur and that a physical condition consistent with easy distribution shall be maintained. If the substances used are difficultly soluble, the fertilizer is not so valuable as one composed of easily soluble constituents. The general solubility of the various ingredients should be known by a prospective purchaser.

The various brands on the market, besides being complete or incomplete, may be designated as high-grade or low-grade. These terms may be used in two ways—high-grade or low-grade as to solubility, or high-grade or low-grade as to amount of plant-food constituents contained. A low-grade fertilizer is the percentage of nitrogen, phosphate acid, and potash is always compared with a large amount of inert material, which adds to the cost of mixing, transportation, and handling. It is thus usually a more expensive fertilizer to a unit of plant-food obtained than one of higher grade. Except for special purposes, a low-grade fertilizer as to solubility should be bought sparingly or not at all.

671. *Fertilizer inspection and control.*—With the many different materials available for making commercial fertilizers, and from the fact that so many opportunities are open for fraud either as to solubility or as to percentage, laws have been found necessary for controlling the sale of fertilizers. Most states have such a law, the western laws generally being superior to those in force in eastern states, where the fertilizer sale is heavier. This is because the western regulations are more strict and the legislators have had the advantage of the experience gained where fertilizers have long been used.

Moreover, the legislators in such states have not been so strongly confronted with fertilizer lobbying, and have consequently been free to enact stricter laws than were possible where fertilizers are such an important commercial commodity.

Usually certain provisions are common to all fertilizer laws. In general, all fertilizers selling for a certain price or over (usually 40 cents) must, say a state license fee and print the following data on the bag or on a label on the bag:—

1. Number of net pounds of fertilizer in a package.
2. Name, brand, or trade-mark.
3. Name and address of manufacturer.
4. Chemical composition or guarantee.

The composition of a commercial fertilizer is ordinarily expressed simply, for example, as a 3-6-10, meaning 3 per cent of nitrogen, 6 per cent of phosphoric acid, and 10 per cent of potash. This, however, is too brief for a guaranteed analysis on goods exposed for sale, as it gives no idea whatsoever regarding the stability of the materials. As might be expected, there is a wide range in the character of the guarantee required by the various states. For example, some states insist on the statement of the percentage of both nitrogen and ammonia, while others insist only on the percentage of nitrogen. Some require the soluble, the insoluble, and the total phosphoric acid, while others require only the soluble and the insoluble. As to potash, it may cover the soluble and the total, while in other cases the total must be given. In general, a guarantee should show not only the amount of the various constituents, but also their form or availability. The guarantee required by North Dakota is typical in this respect:—

Guarantees required by the State of North Dakota.

| | |
|--|---|
| Percentage of N in solution | Percentage of P_2O_5 soluble in water |
| Percentage of N as ammonia | Percentage of P_2O_5 as varied |
| Percentage of N total | Percentage of P_2O_5 is soluble |
| Percentage of K_2O soluble | Percentage of SO_4 total |
| Percentage of K_2O as chloride | |

Since a fertilizer law is designed primarily to protect not only the producers but also the manufacturers, a certain amount of uniformity is allowed below a guarantee. This is a matter of extreme variation in the different states. Ordinarily, also, the offering for sale of any fertilizer under its products, either separately or in packages, is prohibited, unless so stated specifically on the package.

For the enforcement of such laws, the states usually provide adequate machinery. The inspection and analysis may be in the hands of the state department of agriculture, of the director of the state agricultural experiment station, of a state chemist, or under the control of any two of them. In any case, a corps of inspectors is provided, the members of which take samples of the fertilizers on the market throughout the state. These samples are analyzed in laboratories provided for the purpose, & also to ascertain whether the mixture complies in its guarantee. If the fertilizer fails below the guarantee, — allowing, of course, for the variation permitted by law, — the manufacturer is subject to prosecution.

A mass election check on fraudulent guarantees, however, is found in publicity. The state law usually provides for the publication each year of the guaranteed and found analyses of all brands inspected. Not only has

has proved effective in preventing fraud, but it is really a great advantage to the honest manufacturer.

The expenses for the inspection and control of fertilizers are usually *delayed* by the *harvest loss*, which averages for the different states from ten to twenty dollars a year for each brand selling for \$5 or more a ton. In the United States this loss produces a net return, *grossly* in case of the expenses incurred by the fertilizer inspectors and control, and consequently has become the source of a *harvest loss* for these states.

478. *True value of fertilizer*.—It has become customary for the collection charged with fertilizer inspection and control in the various states to adapt each year a schedule of the trade values of the various elements as they appear on the market in various lots. These values are obtained by averaging all the wholesale prices of a ton for the various unsegregated samples for the six months preceding March 1, to which is added 20 per cent of the price to cover cost of handling. The trade values for 1913 were as follows:¹

| TRUE VALUES OF FERTILIZER ELEMENTS IN THE MARKET AND CURRENT | |
|--|------------|
| | On a pound |
| Nitrogen in ammoniac salts | 18¢ |
| Nitrogen in nitrates | 18¢ |
| Organic nitrogen in dry and fine fish, meat, and blood | 20 |
| Organic nitrogen in fine bones, tankage, and animal fertilizer | 10 |
| Organic nitrogen in coarse bones and tankage | 15 |
| Organic nitrogen in coarse poultry and mill animal meal | 20 |

¹New York (Hewitt), *Ag. Rep.* No. 782, p. 271, p. 284, 1913.

| | Grade a price |
|--|-------------------------------|
| Phosphoric acid, water-soluble | 4 ¹ / ₂ |
| Phosphoric acid, citrate-soluble (precipitated) | 4 |
| Phosphate acid, in the bone, fish, and sewage | 4 |
| Phosphate acid, in cottonseed meal and cattle manure | 4 |
| Phosphoric acid, in coarse fish, bone, shavings, and sawdust | 3 ¹ / ₂ |
| Phosphoric acid in mixed fertilizers, insoluble in water or ammonium chloride | 3 |
| Potash as high-grade sulfate, in fertilizer from chlor- ides, in ashes, etc. | 4 ¹ / ₂ |
| Potash as carbonate | 4 ¹ / ₂ |
| Potash as other potasses and ammonium nitrate | 4 |

It must be remembered that these prices are railroad evaluations, and represent the cost to the manufacturer of the elements as they exist in the mineral source. This is called the commercial evaluation of a fertilizer, and is the first of a number of items that enter into the total cost, or the price the farmer must pay on the retail market. The items that make up this ultimate price may be listed as follows: (1) wholesale cash cost, or no special evaluation; (2) cost of making; (3) profit of manufacturer; (4) transportation; (5) storage; com- mission to agents, haul labor, and so forth; and (6) profit of retailer. These additional charges are often sufficient to double the original commercial value of the fertilizer constituents.

It is evident that by knowing the composition of a fertilizer, and the nature of the various components, the commercial evaluation of the mixture may be easily estimated. However, what the farmer must pay depend-

is a large extent on the additional charges already listed. Thus, a fertilizer estimated at \$32 a ton on the New York market may cost the farmer \$35, or even \$40, after having passed through the hands of the manufacturers and the retail merchant. This commercial evaluation, however, need not be confused with the agricultural evaluation, which is the value of the increased crop produced by the application of the fertilizer. It is evident that the agricultural value will vary with the soil, the crop, or the season, and may be above or below the total cost according to circumstances. In good fertilizer practice, the excess of the agricultural value over the total cost of the fertilizer, all costs incidental with the growing, harvesting, and marketing of the increase being first deducted, should be sufficient to give a handsome profit on the investment.

42. *The buying of mixed goods.*—The successful buying of mixed fertilizers on the retail market depends on two things: (1) the selection of a suitable composition, with varieties of known value; and (2) the purchase of high-grade goods. The farmer who observes these two points will have at least purchased successfully. Whether he obtains a profit from the use of the fertilizer depends on the balancing of a number of factors more or less variable from season to season.

The selection of a suitable fertilizer, as to varieties and composition for any particular crop or soil, results first of all a study of the guarantee. Should the guarantee be such as that already cited, a large amount of information is at hand concerning the forms of the various and the availability of the important constituents. This knowledge, properly connected with the probable needs of the crop and the soil, will determine whether that

is much per ton to market a low-grade material as a high-grade one. This accounts for the fact that the amounts are cheaper per pound in a high-grade material, and that the value of plant food received for every dollar expended is greater.

29. Heavy machinery. In comparing the above commercial estimations with the prices actually paid by the farmer on the retail market, it is found that the latter shows an increase ranging from 40 to 100 per cent. The index to the charges for mining, transportation, handling, storage, insurance, interest on capital, profits, and other items, made during the passage of the material from the wholesale dealer to the user. In order to escape these costs, many farmers have begun the practice of buying the separate machines, thus avoiding these charges—except, of course, that of transportation. In many cases the saving on the farm costs nothing, as it can be done in winter when the farm work is not pressing. Even if the farmer must charge himself with the mining, it seldom amounts to more than fifty cents a ton.

As might be expected, this practice has not led to much expenditure from manufacturers. In general it is allowed that the factory goods are more. Early passed this those raised by the farmer, and consequently the rationalized goods are not only more uniform but also in better physical condition. Also, the manufacturer is able to treat various materials with acids, and thus increase their availability. While these reasons are more or less valid, good results may be expected from a better even though it may not be quite uniform, as the soil tends to equalize its delivery. However, by sowing and by using a proper tiller, a farmer can obtain a physical condition which will in no way interfere with the drilling of the soil.

trial. While, typically, one farmer alone cannot afford to buy direct from the wholesale dealer because of the high freight charges on small lots, this objection is being met by states and various organizations whereby the single carriers may be brought in reduced lots.

It is evident that when a farmer mixes his own fertilizer he is able to obtain not only pure goods, but *hygienic* goods as well, thus reducing freight. Moreover, as a general thing home mixing is cheaper than buying the analysed goods. A quotation from Coover¹ for 1906 illustrates about what this saving may be:—

PLANT FOOD PURCHASES FOR 1901

| | Pounds Purchased | | | Price |
|---------------------------------|------------------|-------------------------------|------------------|-------|
| | N | P ₂ O ₅ | K ₂ O | |
| <i>Margarine superphosphate</i> | | | | |
| Best quality | 75 | 100 | 115 | 272 |
| Lowest reliable | 25 | 272 | 50 | 85 |
| <i>Special manure</i> | | | | |
| Best quality | 69 | 170 | 140 | 382 |
| Lowest quality | 35 | 174 | 81 | 257 |
| <i>Worm manure</i> | | | | |
| Average of all | 77 | 206 | 187 | 495 |

A third point, and by some considered to be more important than those already discussed, is the educational value of home mixing. No farmer can mix his own fertilizer without becoming familiar with the various, their availability, and their effects. He is forced to study their influences as the recipe more closely, and thus is placed

¹ Jenkins, R. H., and Martin, A. L. *Fertilizer Research. (New Plants)* Agr. Expt. Sta., Rept. 1063, Part I, pp. 1-106.

is a promise to make changes that will lead to a higher efficiency of the combination. The chances are that he will alter his fertilizer system as his methods improve and his soil changes in fertility.

Such arguments do not always count, however, that is, page to me at home. As a matter of fact, in many cases it does not pay, especially where only a small amount of fertilizer is needed and it is impossible to compare with other losses. As a general rule, fertilizers should be bought by the method that will give the greatest value for every dollar expended. Farmers often can avoid the expense of the advantage of both systems by asking for bids from various manufacturers on ordered lots of mixed goods having a certain designated composition. The farmer in this case designs the mixture as well. All the advantages of machinery mixing may thus be joined with the lower cost which has made home mixing a reality.

45. *Fertilizers not to be mixed.*—Every farmer who practices horse mixing should keep in mind that there are certain fertilizers which should not be mixed. This is due to the fact that a number of materials carry lime in the acids, the hydroxide, or the carbonate form. This lime, particularly the caustic form, may react in these mixtures, depending on the fertilizers with which it is mixed: (1) in setting free ammonia, (2) in causing the loss of acid phosphate, and (3) in producing a bad physical condition, especially when it reacts with superphosphates or less deliquescent. Van Slyke¹ says in regard to this matter as follows:—

¹ Van Slyke, A. L. *Fertilizers and Crops*, pp. 435-436. New York, 1912.

SOIL ACIDS; FERTILIZERS AND MANURE

| | | | |
|----|------------------------|---|----------------------|
| 1. | Calcium oxide | should not be mixed with | ammonium sulphate |
| | Calcium hydroxide | | nitric manure, |
| | Wood ashes | | or twigs, |
| | Basic slag | | blood, and the like |
| | Calcium cyanamid | | nitrogenous |
| 2. | Basic calcium sulphate | should not be mixed with | gypsum |
| | Calcium oxide | | |
| | Calcium hydroxide | | |
| | Calcium carbonate | | white phosphorus |
| | Wood ashes | | of any kind |
| 3. | Basic calcium nitrate | should not be mixed with (sulphuric acid immediately) | sodium nitrate |
| | Calcium oxide | | potassium chloride |
| | Calcium hydroxide | | nitric acid |
| | Basic calcium nitrate | | biuret, and the like |
| | | | |

Neither is it wise to allow nitric acid phosphate to be in contact with large quantities of sodium nitrate, as nitric acid may be slowly liberated by free sulphuric or phosphoric acid. Also, large quantities of sodium cyanamid should not be mixed with acid phosphate because of the lime contained in the former. If, however, the ratio is not greater than one to ten, the results are beneficial, since the reaction, without causing serious retention of the phosphate, generates enough heat to quickly warm the mixture. The fine and dry condition of the cyanamid is also conducive to a good mechanical combination, and accounts for the fact that this material is in such favor with manufacturers of mixed goods.

49. *How to mix fertilizer*—As the various sources are brought under question, the percentages of nitrogen, phosphoric acid, and potash in the ingredients to be mixed are necessarily known. The calculation of the amounts of each carrier and of the filler necessary to make up a ton of a fertilizer having a certain formula, then becomes a matter of simple arithmetic. The mixing is an equally simple operation. The implements needed in home mixing are as follows: (1) a tight floor, (2) platform scales, (3) a small screen with from three to six meshes to an inch, (4) a harrow or a grider, (5) shovel, a rake, and like tools.

First, the various ingredients, after being crushed and screened if lumps, are weighed out in amounts sufficient for the unit of fertilizer to be mixed at any one time. The heaviest material is spread on the floor first and leveled uniformly by raking. The remaining ingredients are then spread in this layer above the first, in the order of their bulk. Beginning at one side, the material is not shoveled over, care being taken that the shovel reaches the bottom of the pile each time. The pile is then again leveled, and the process is repeated a sufficient number of times to insure thorough mixing. Sometimes a mixing machine may be used for this operation. For storage and general convenience, the fertilizer may be weighed from sacks of from 100 to 500 pounds quantity and put in a dry place until needed for use.

A word of caution should be heeded here regarding the transportation of the mixture. Name, however, in order to lessen the shock of mixing and application in the field, twice the percentage of the elements exceedingly light in weight very likely to occur when high grade materials are used. This is best practice, in that it may interfere

with germination and may also injure the young plant. Also, it is likely to result not only in a poor physical condition but also in uneven distribution, which will bring about a lowered efficiency of the fertilizer. The use of surface-dry, finely divided fertilizers will obviate such dangers.

47. Factors affecting the efficiency of fertilizers. — The agricultural value of a fertilizer is necessarily a variable quantity, since, in applying fertilizers, a material subject to change is placed in contact with two wide variables, the soil and the crop. The general factors that govern the effect of fertilizers may be listed as follows:

1. *Kind, crop, and adaptation of crop to soil.* — It is quite evident that different crops will respond differently to the same fertilizer elements. Also, the strength of the soil, the management of the crop, and the adaptation of crop to soil, will be potent factors in variation.
2. *Temperature, moisture, and rainfall.* — These factors are environmental and, of course, are dominant in the growth of the plant. Rainfall especially is important, as an optimum moisture content is conducive to good plant development. In general, as shown by experiments in Ohio and Pennsylvania, the higher the rainfall, the greater is the efficiency of the fertilizer used.
3. *Deepness.* — This is of great importance in fertilizing practice, since it places the soil in a better condition from all standpoints for plant growth. In other words, the better the normal soil conditions, the better should be the reaction from fertilizing application.

6. *Physical condition of the soil.*—The addition of lime and organic matter, the utilization of cloverings, tillage, and the like, all are conducive to higher crop returns through the indirect effect on fertilizer efficiency.
5. *Lime.*—Lime, by improving physical conditions, by setting plant-food free, by increasing acidity, by stimulating bacterial action, and by tending to stimulate toxic materials either directly or indirectly, is of great importance in fertilizer practice. In fact, certain fertilizers, such as ammonium sulfate and acid phosphate, do not reach their full efficiency unless plenty of lime is present.
6. *Organic matter.*—Besides the effect of organic matter on physical conditions and chemical reactions which indirectly influence fertilizer action, an important action is set up by organic matter in the maintenance of bacterial functions. In the favorable changes of fertilizers, especially those nitrogenous, oxygen, is due to biological activity, the presence of organic material becomes highly important.
7. *Chemical composition of the soil.*—Since the full return from a fertilizer is derived when the elements are well balanced, the actual composition of the soil becomes a factor, especially when ready availability is obtainable. Therefore, in choosing a fertilizer and deciding on the amounts to apply, the elemental condition of the soil is an important factor.

While the conditions affecting fertilizer efficiency have been so briefly discussed, it is evident that a com-

detailed consideration of the question would be not only interesting but also profitable, would spare pen-
cils. The point of broader scope, however, that the addition of a well-balanced food stimulation, stands out clearly in this consideration. The necessity of putting a soil in any given climate into the best possible condition for plant growth is paramount. This means that drainage, lime, humus, and things, in the order named, must be raised to their highest perfection. Under such improvements the further use of commercial fertilizers may or may not be a paying investment.

176. *Method and time of applying fertilizers.*—The distribution of the fertilizer by means of machinery is much more satisfactory than is broadcasting by hand, as the former method gives a more uniform distribution. Cereals and other crops are now usually planted with a drill or a planter provided with an attachment for dropping the fertilizer at the same time that the seed is sown, the fertilizer being by this method placed under the surface of the soil. Broadcasting machines are also used, which leave the fertilizer uniformly distributed on the surface of the ground, thus providing it to be homogenized in soil shortly before the seed is planted, and preventing injury to the seed by the chemical activity of the fertilizer material.

Corn planters with fertilizer attachments deposit the fertilizer beneath the seed, thus avoiding a possible detrimental contact. Grain drills do not do this, and, where the amount of fertilizer used exceeds 300 or 350 pounds an acre, it is better to apply it before sowing. Grass and other small seeds should be planted only after the fertilizer has been mixed with the soil for several days. For crops to which large quantities of fertilizer

are to be added, especially potash and garden crops, it is desirable to drop only a portion of the fertilizer with the seed, the remainder being broadcast by machinery and harrowed in order.

479. *Fertilizing crops.*—Three primary considerations must be observed in the actual utilization of fertilizers: (1) the percentage of nitrogen, phosphorus, and potash added to the crop and the soil; (2) the availability of the carriers; and (3) the amounts to be applied. It is not that, due to so many factors that are difficult to control, the fertilizer formulas for different crops or particular soils are difficult to determine. In fact, such data can never be more than merely suggestive. Further, the best quantity of a mixture to apply, even though it is perfectly balanced, is a figure that can only be approximated. Probably the largest percentage of the fertilizers sold that come annually are broadcast in this fashion. Many farmers make the mistake of applying too much fertilizer. As a consequence, any information along such lines can only be merely suggestive, rather than formal, it being understood that the general formulas suitable to various crops, and the quantities reflexly applied, are subject to wide variations.

The fact that there are so many mixtures on the market in this country for the same crops would be rather amusing, did it not so strikingly expose the ignorance of the manufacturers as well as the gullibility of the public. Recognizing the need of standard formulas subject to change according to local conditions, Van Slyke¹ has offered the following for general use:

¹Van Slyke, L. L. *Fertilizers and Crops*, p. 53. New York, 1912.

NUTRIENT POTENTIAL FOR COMMON LEGUMINOSAE

| Crop | Percentage of N | Percentage of P ₂ O ₅ | Percentage of K ₂ O |
|-----------------------|--------------------|--|-----------------------------------|
| Leguminosae | 1 | 8 | 10 |
| Cereal | 3 | 8 | 5 |
| Grasses | 4 | 8 | 10 |
| Grain | 2 | 6 | 3 |
| Grassland | 5 | 5 | 10 |
| Root | 3 | 8 | 7 |

While it is recognized that these formulas are probably far from correct in their application to such groups as the garden crops, where so many widely different plants are concerned, it is felt that they furnish the basis, at least in our knowledge now existing, for a more economic fertilization. The question of such mixtures is not specifically made a part of fertilizer practice.

The cures largely used for such readily available nutrients are sodium nitrate, acid phosphate and potassium chloride or sulfate. Potash or blood is often substituted for sodium nitrate where luxury is desirable, while ammonium sulfate and calcium cyanamide are growing in popularity. Bone rock phosphate and basic slag are used rather largely in separate applications, the amounts being usually larger than with the ordinary fertilizer materials.

The other phase of fertilizer practice is in the amount to be applied. With all the groups considered above except garden and root crops, the applications are relatively light, ranging from 150 to 300 pounds to an acre. Where excessive vegetative growth is required, as in hay, the rate may be increased to 500 pounds. In the hay fields of meadows or pastures, the rate varies from 25

in 100 pounds in acre. Very often this dressing is within limits alone. With guano and root crops the amount of fertilizer applied is very large, ranging from 500 to sometimes as high as 2000 pounds. The cropping here is extensive, and the expenditure for fertilization may be large and yet yield handsome profits.

It must always be remembered that in fertilizer practice the very high yields obtained under fertilizer stimulation are not always the ones that give the best returns on the money invested. In other words, the law of diminishing returns is a factor in the influence of fertilization on crop yield. This relationship is clearly shown by the curve illustrating the law of the maximum (page 461), in which the return for each increment of fertilizer becomes less and less as the total quantity added becomes greater. It is evident, therefore, that with an excessive application of any manure, the return to an investment will at last become so small that the forward crop fails entirely to pay for even the fertilizer, not to mention such charges as cost of application, harvesting of increased crop, storage, and the like. The application of moderate amounts of fertilizer is to be resorted to for all soils until the maximum paying dose that may be applied to any given crop is ascertained by careful experimentation. Over-fertilization probably accounts for the fact that such a large proportion of the fertilizers sold to the farmer each year are not only so entirely wasted, but probably in some cases even become detrimental to crop yield.

40. Systems of fertilization.—During the evolution of fertilizer practice, particularly since the early part of the nineteenth century, a number of systems of applying fertilizer have been advocated or have been in actual use. These may be listed as follows:—

1. *Single-element system.*—This was one of the first to be suggested, and was advocated because each particular crop was supposed at that time to respond largely to one element. Thus, nitrogen was supposed to dominate wheat, rice, and oats; phosphoric acid, to dominate corn, sorghum, and sorghum; and potash to dominate potatoes, clover, and beans. Present knowledge of the balancing effects of fertilizers shows this idea to be fallacious.
2. *Absent supply of minerals.*—This system had its origin from the fact that potash and phosphoric acid are relatively cheap and are slowly leached from the soil, while nitrogen is expensive and easily lost. Such a plan, therefore, provides always plenty of potash and phosphorus, which is to be balanced each season with sufficient nitrogen to give paying yields.
3. *A system based on the phosphate taken out by the crop.*—According to this plan, as much phosphate is added each year as will probably be taken out by the plant, this being determined by chemical analyses. This system overlooks the fact not only that different plants feed differently on the same soil, but that the same crop exhibits marked variability with change of season and change of soil. Moreover, no allowance is made for losses by leaching, which are known to equal at times the loss due to plant growth.
4. *Rotational system.*—This is the plan followed by many farmers when the soil is known as important factor in soil management. The formula is changed from year to year, in a vain attempt to utilize

high price in production. The conventional view is based on the quantity supplied. For when the specific forest land is determined by the state, it is not that it exists or by the remuneration of the small landowner, rather than from a careful consideration of the parameters of all the estates for each important element. The structural plans of forest estate should do much to develop this system.

1. *Production of the money crop.*—In forestry as in general farming operations one crop is usually a money crop. Naturally its stimulation by heavy fertilization will pay better than application to crops that bring less on the market. The general plan in this system is to allow the crops following the money crop to utilize the wealth. When this residual fertilizer works out, the system is likely to be a profitable one; but when the following crops fail to respond, the method becomes wasteful in the extreme.

In the selection of a system that will result in an effective utilization of fertilizers, only one of the plans described above need be considered. In any fertilizer, phosphate rock and potash should always be present in amounts sufficient to meet the balance of the nitrogen, since the activity of nitrogen is so pronounced. Therefore a scheme that calls for an abundance of minerals is a sound one. This, coupled with the heavy fertilization of the money crop, does not, however, constitute what might be considered a rational system, since the crops that follow may or may not be adequately supplied with phosphate. (Lower fertilization often forces the soil,

as far as its balance is concerned, less able to yield a paying crop than before. The careful fertilization of the rotation, then, with special attention to the money crop, is the only rational system that can confidently be employed, since it not only *repays* for the crop on the land but also looks to those that are to succeed. The attention that must necessarily be paid to the fertility of the soil in such a system insures the establishment of a soil management which will ultimately result in a great conservation of fertility, while at the same time raising the yields and increasing the prosperity of the farming class.

CHAPTER XXVI.

FARM MANURES.

Of all the by-products of the farm, manure measures probably the most important, since it absorbs a mass whereby the unused portion of the crop, the residue of the finished farm product, may again be returned to the soil. This country is now entering an era in which the preservation of all waste is becoming more and more necessary and a wiser approach to a re-fashioning system of agriculture far more essential. A clear understanding of the composition of farm manure, the changes it undergoes, and its avenues of loss, and also of methods for its practical handling, and a realization of its effects both on soil and on crop, are of vital importance. This need appeals not only to the practical man, but to the theoretical and technical man as well, for here is a field in which theory and practice not only meet but vitally overlap.

XXI. General character and function of farm manures.

The farm manure may be considered in reference to the value from all animals of the farm, although, as a general rule, the bulk of the ordinary manure which ultimately finds its way back to the land is produced by cattle and horses. This arises not only because these animals consume the greater part of the grain and roughage on the average farm, but also because the methods of handling them render it easier and more practicable to

preserve their contents. Yard manure generally refers to mixed manures. The mixing usually occurs during storage, either for convenience in handling or for the purpose of checking losses and facilitating fermentation. Thus, horse and cow manures are commonly mixed, since the two rapid fermentation and probably loss of ammonia in the former is checked, while at the same time a more acid and much more complete decay is encouraged in the latter.

The ordinary manure consists of two original components, the solid and the liquid portion. As these constituents differ greatly, not only in composition but also in physical properties, their proportions must appreciably affect the quality of the manure and its agricultural value. Litter added for bedding or for absorptive purposes is almost always an important factor, for while it prevents losses of the soluble constituents it may at the same time lower the value of the product for a soil manure.

Yard manure actually fulfills two functions which are usually not so distinctively yet clearly developed in any other material—that of a direct soil that of an indirect fertilizer. Consisting of 71 per cent of water and only 27 per cent of dry matter, the percentages of plant-food are necessarily low. As mixed farm manure contains on the average 0.50 per cent of nitrogen, 0.25 per cent of phosphoric acid, and 0.40 per cent of potash, considerable quantities of plant-food elements are added in an ordinary application. The ton of average manure, even if only one-half of the nitrogen, one-third of the phosphorus, and one-fourth of the potash are readily available, is equivalent to 300 pounds of sodium nitrate, 16

*See *Analyses*, *Report R. H. Appleton*, pp. 287-318 New York: 1916.

pounds of acid phosphate and 125 pounds of potassium chloride. This is equivalent to the addition of 586 pounds of an approximately 10-5-12 residential fertilizer. Moreover, from the fact that so large an amount of the phosphate carried is not readily available, it acts as a reserve, which is slowly given up to the succeeding crops. It has been shown in England¹ that paying increased returns may be obtained from manure four years after its application. At Titchmarsh, England,² a residual nitrogen was noticeable on crops forty years after its soil was manured. This, however, is an exceptional case.

Farm manure may act as an indirect fertilizer in its tendency toward improved physical relations. The addition of organic matter in the soil favors better tilth, better aeration, improved drainage, and increased water capacity are the necessary accessories to a rise in humus content. The influence of manure on the availability of the mineral constituents of the soil is not the least of its indirect effects. Even the increased absorptive power of the soil should be mentioned, in its tendency toward the concentration of toxic principles.

Another general characteristic of average farm manure is that, while it is a fertilizer, it is an unbalanced one. Unproportional very largely to a 10-5-10 commercial mixture, any one compared with general fertilizer practice can see that it is too high in nitrogen and too low in available phosphoric acid. The elimination of such a consid-

¹Woodward, J. A., and Hall, A. B., *The Utilization of Farm Manure Manured by the Consumption of Fertilizer* (2d. Edn., London, 1905).

²Id., A. B., *Fertilizers and Manure*, p. 232. New York, 1910.

tion and a balancing theory of the plant system is one of the many problems that present themselves in the economic handling and utilization of animal resources.

492. Variable composition of manure.—The manure produced on an average farm is rather likely to vary markedly in composition and character from time to time. It may even change radically from one day to another. There are five general factors that are usually listed as being responsible for this variation: (1) litter; (2) class of animal; (3) individuality, condition, and age of animal; (4) feed of animal; and (5) handling of manure.

493. Litter. Perhaps under ordinary circumstances the amount and character of the litter has so much to do with the variation in manure composition as has any other one factor, if not more. By an increase in the amount of bedding, the product becomes bulkier, light in weight, and difficult to handle. This is likely to be the case with manure from heavy milks, where the litter is used to keep the horses clean and not for purposes of placidated conservation. That bedding must also exert a marked effect on chemical composition is evident from the following analysis:—

| Composition of Litter | | | |
|----------------------------|------|------|------|
| | % | lbs. | tons |
| Bedding shavings | 0.00 | 4.29 | 6.40 |
| Gas waste | 0.00 | 0.29 | 0.04 |
| Peat | 2.50 | 9.30 | 0.17 |
| Lime | 0.00 | 0.15 | 0.00 |

Shavings and shavings add little of value to the product and really act as a diluent. While they are good absorb-

on their despatch as simply as to make them somewhat adjustable on light soils. Leaves despatch readily, but not fully thereby. Cut shows roots as more showy than does average measure, but the nitrogen, the shot of post or work, is not really available as plant food. Litter, however, is of real value as support as is evident that the residue quality of one and another as always can be to a degree ignored. The case of the influence of the bedding on composition, nature should never be thought when this place has been carefully looked into.

85. Case of animal.—The second factor causing total variation in the composition of firm nature is the class of animals which it represents. The following figures, compiled from Olm, (American, and New York for Cornell University), illustrate this point clearly:—

| | Percentage of | | | |
|------------------------|---------------|------|------|------|
| | Mo | N | P | K |
| Firm nature with close | 62.00 | 0.95 | 0.10 | 0.14 |
| Over nature with close | 70.00 | 0.40 | 0.12 | 0.26 |

A feeding house on maintenance value will show in the matter about all the nitrogen and minerals taken as food. In other words, the bedding and the breaking down, or elimination, process are about equal. A good feeding pig, on the other hand, will return only about 35 per cent of the nitrogen received as food and 16 per cent of the mineral material, and a milking cow 76 per cent and 69 per cent, respectively.

¹Thomas C. B. Patten, *Massachusetts*, New York, 1914.

398. Individuality, condition, and age of animal. — Various animals differ in capacity, some retaining much more of the elements contained in the food than do others, and consequently producing a poorer measure. The service to which the animal is subjected is also a factor. A sildik cow will certainly utilize more nutrients than an animal not in that condition. Age is perhaps more accountable for variation in farm measure than either of the other two causes. A young animal gaining in track and bone is storing away large quantities of nitrogen, phosphorus, and potash, and producing a measure correspondingly poorer in these ingredients.

400. Food of animal. — Since the animal will retain only a certain quantity of the food elements, it is reasonable to suppose that the richer the food, the richer will be the corresponding excrement, both liquid and solid. Such has proved to be the case. "Wander" in studying the nature of chickens, found the following difference in the manure produced:—

| Dietary | Composition of | | | |
|--------------------------------------|----------------|------|------|------|
| | 100 | A | P | B |
| Produce manure (average value) | 16.7 | 1.20 | 0.41 | 0.27 |
| Produce manure (poor houseman value) | 55.5 | 0.66 | 0.26 | 0.21 |

From Ohio, where the production of manure has been most thoroughly investigated, the following data may be quoted:—

¹Whipple, W. P. *Trailing Working Horses*. New York: (Ginn) Agr. Exp. Sta., No. 8, p. 44, 1883.

²Thomson, C. R., and others. *The Measurement of Fertilizer*. Ohio Agr. Exp. Sta., Bul. 132, 1897.

TABLE 1
PERCENTAGE OF LOSS OF VITAMIN C IN THE PREPARATION OF PLASTICIZED POLYESTER

| Sample | Percentage loss of Vitamin C | | |
|--------------------------|------------------------------|-------|------|
| | Initial | Final | Loss |
| Control (no plasticizer) | 1.00 | 0.95 | 0.05 |
| Control (no plasticizer) | 1.00 | 0.90 | 0.10 |
| Control (no plasticizer) | 1.00 | 0.85 | 0.15 |

of handling material.—In dealing with a product of which almost one-half is liquid, there is great danger that a considerable amount of valuable plasticizer will be lost by leaching. The modification and consequent lowering of the plasticizer value of these samples is a real question in the economic handling of this product. Next to the effect, lack of size is perhaps the most important single factor concerned in achieving the desired composition of samples in general. The influence of handling is so clearly brought out by the following figures from Table 1, on actual losses and on losses, that further discussion seems unnecessary. The plasticized material in this case was in a box under a steel. The exposed sample was in a similar bin but unprotected from the weather.

| Sample | Loss of Vitamin C in the weather (Percentage) | | Loss of Vitamin C in the weather (Percentage) | |
|--------------------------|---|-------|---|-------|
| | Initial | Final | Initial | Final |
| Control (no plasticizer) | 1.00 | 0.95 | 1.00 | 0.95 |
| Control (no plasticizer) | 1.00 | 0.90 | 1.00 | 0.90 |
| Control (no plasticizer) | 1.00 | 0.85 | 1.00 | 0.85 |

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681 Composition and character of farm manure.—Although the probable composition of farm manure is as difficult to state in exact figures, compilations of the available data have yielded percentages which, while they demand a most liberal interpretation, afford considerable light regarding the differences that normally exist between the excrement of various animals. Of these compilations, Van Slyke's is perhaps the best.

THE COMPOSITION OF FARM MANURE¹

| Manure | | Percentage | | |
|--------|--------------------|------------|------|-------|
| | | Mo. | N. | Mo. |
| Horse | Solid 60 per cent | 75 | 0.85 | 0.40 |
| | Liquid 30 per cent | 80 | 1.05 | Trace |
| | Whole manure | 78 | 0.70 | 0.35 |
| Ox | Solid 70 per cent | 85 | 0.80 | 0.50 |
| | Liquid 30 per cent | 85 | 1.00 | Trace |
| | Whole manure | 85 | 0.90 | 0.45 |
| Sheep | Solid 67 per cent | 60 | 0.75 | 0.55 |
| | Liquid 33 per cent | 88 | 1.25 | 0.05 |
| | Whole manure | 78 | 0.85 | 0.50 |
| Pork | Solid 65 per cent | 80 | 0.85 | 0.50 |
| | Liquid 35 per cent | 87 | 0.80 | 0.05 |
| | Whole manure | 87 | 0.80 | 0.40 |

Since the horse does not excrete its food, the manure is likely to be of an open character. It is also a fairly dry manure, as is that from sheep, the liquid in these two manures making up 30 and 33 per cent, respectively, of the whole product. The complete manure from these two animals contains 78 and 68 per cent, respectively,

¹ Van Slyke, L. L. *Barthman and Cochr.* p. 291. New York, 1912.

of water—a considerably constant to the 35 and 37 per cent presented by the critic and police measurements. (Salt and saline measures, being very wet, are neither solid and compact. The air, therefore, is likely to be excluded to a large degree and decomposition is relatively slow. They are usually spoken of as cold, and measure is compared with the dry, open, rapidly heating measure whisked from the basin and the stove.

In every case except that of wine the liquid portion of the various elements is much the value in volume, judging on the average more than twice as much when compared on the percentage basis. The liquid is also richer in value than the solid, averaging for the four classes of animals 1.36 per cent as compared to 0.54 per cent contained in the solid measure. Most of the phlogestoid, however, is contained in the solid component, only traces being found in the entire except in the case of the wine. It is therefore evident that the liquid measure, pound for pound, is more valuable in so far as the phlogestoid elements are concerned. The advantage here, however, toward the wine also is that the waste water does not remain so immediately available; this cannot be said of the solid measure.

III. Actual phlogestoid in liquid and solid component.—While the liquid measure carries more nutrients in an equal weight than the solid, it yet remains to be seen which actually carries more of the phlogestoid food elements. In pound, more solid measure is consumed than liquid, leading to these advantages toward the former in so far as total food elements are concerned. The following table, adopted from Van Slyke,¹ bears on this point:—

¹Van Slyke, A. L. *Proteins and Craps*, p. 363. New York, 1912.

DETERMINATION OF PLANT PART COMPOSITIONS CORRELATE THE
LIGHT AND THE SOILS OF WISCONSIN HAYFIElds

| Nutrient | Proportion of Total Nutrient | | Proportion of Total Nutrient in Stems | | Percentage of Total Nutrient | |
|---------------------------------------|------------------------------------|------|---|------|------------------------------------|------|
| | Root | Stem | Root | Stem | Root | Stem |
| Hydrogen | 42 | 35 | 100 | 0 | 48 | 40 |
| Oxygen | 48 | 51 | 100 | 0 | 56 | 50 |
| Starch | 55 | 40 | 90 | 5 | 50 | 30 |
| Soluble | 77 | 30 | 10 | 12 | 37 | 42 |
| Average | 57 | 41 | 15 | 0 | 40 | 40 |
| Average for hay and cane | 56 | 45 | 100 | 0 | 55 | 65 |

It is seen here that a little more than one-half the nitrogen, almost all the phosphoric acid, and about one-fifth of the potash, are found in the solid matter. Nevertheless the apparent advantage of the solid matter is balanced by the ready availability of the nutrients carried by the juice, giving it in total about as equal commercial and agricultural value with the solid component. Such figures are suggestive of the care that should be taken of the liquid manure. The ready loss of nutrients by fermentation, and the ease with which its valuable constituents may escape by leaching, should make it an object of especial regard in handling.

420. *Production of manure.*—A well-fed, moderately worked horse will produce daily from 45 to 55 pounds of manure, of which from 10 to 15 pounds is urine. A cow, on the other hand, having a greater food quantity, will excrete from 70 to 90 pounds during the same period, of which from 30 to 35 pounds is liquid. Swine and

directly varying so greatly in weight, will require not only different quantities that it is difficult and misleading to express the amount based on the individual. A clearer method of comparison is that employed below, in which a thousand pounds in weight of manure is made the basis of the calculation:—

RELATIVE BENEFIT OF MANURE FROM MANURE TO THE FARM
PERMANENTLY MANURED

| Manure | Weight of Manure | Value of Crop |
|--------|---------------------|------------------|
| Manure | 1000 | 100 |
| Crop | 20 | 100 |
| Manure | 40 | 100 |
| Manure | 60 | 100 |
| Manure | 80 | 100 |

It is quite evident that, for the weight of manure, the value and the use give the heaviest production of manure on the farm, but it should be remembered also that they contain the greatest amount of food. Whether these manures are the most economical in production of manure thus depend largely on age and individuality.

¹ Roberts, J. P., and May, H. E., On the Production of Permanent Manure by Land and Manure. *General Rep. Agr. Exp. Sta.*, Vol. 15, 1900. Also, Roberts, J. P., On the Production and Use of Farm Manure. *General Rep. Agr. Exp. Sta.*, Vol. 27, 1891. Also, Watson, G. C., The Production of Manure. *General Rep. Agr. Exp. Sta.*, Vol. 28, 1892.

² Watson, G. C., Farm Manures, p. 57. New York, 1914.

³ Watson, G. C., and others, The Measurement of Fertilizer. *Gen. Rep. Agr. Sta.*, Vol. 103, 1897.

⁴ Watson, G. C., The Production of Manure. *General Rep. Agr. Exp. Sta.*, Vol. 27, 1891.

⁵ The Fertilizer, G. L. Fertilizer and Crop, p. 204. New York, 1912.

481. *Hayden's formulae.*—Perhaps a better and more nearly accurate means of calculating the probable production of manure is from the feed consumed, rather than from the estimated weight of animals kept. Formulas have been devised from experimental data in Germany and are designated as Hayden's formulae.¹ From the amount of absolute dry matter fed and the conversion produced, Hayden was able to determine certain definite relationships of the latter to the former. These, of course, varied for different animals, being 2.10 for the horse, 1.69 for the cow, and 1.00 for sheep. For example, if a horse received 20 pounds of dry matter daily, the manure produced would be 42 pounds. Such formulae are of particular value on English farms, where the incoming rents must pay the growing tenant for the manure produced on the farm during previous years.

482. *Poultry manure.*—The manure from poultry is extremely variable, due to causes that have already been discussed. In general, this manure is much richer than that from other farm animals. Shreve² gives the following analysis:—

| Composition of Poultry Manure | |
|-------------------------------|----------|
| | Per cent |
| Water | 0.06 |
| Nitrogen | 1.60 |
| Phosphoric acid | 1.75 |
| Potash | 0.90 |
| Lime | 2.35 |

¹Therry, F. A. *Feeds and Feeding*, p. 303. McGraw-Hill: New York, 1906.

²Shreve, R. D. *Agribusiness*, Vol. 1, p. 112. New York, 1903. Also, Wilson, E. B. *Ground Bone and Manure*. New Jersey Agr. Exp. Sta., Bul. 94, 1881. 1906.

It is evident that poultry excrement is the most valuable manure produced on the farm. It does readily rot the best of nitrogen by fermentation is not good. Because of its great strength farmers are very careful regarding its application, as injurious effects on the crop may result. Notwithstanding its great value it probably receives less care than any other manure produced on the farm.

121. *Commercial and agricultural evaluation of manures.*—For purposes of comparison, experimental and sale, barn manures are often evaluated in a way similar to that used with commercial fertilizers. The great difficulty here lies in arriving at prices for the important constituents which are at all comparable with the value of the manure in the field. The following figures are calculated from the preceding tables, and show not only the comparative value of the fresh excrement from different sources but also what might be considered as fair prices to pay for the manures. The value of the nitrogen is here placed at ten cents a pound, the phosphoric acid at four and one-half cents, and the potash at four cents:—

| | Value of manure a ton |
|--|-----------------------------|
| Stable manure | \$1.50 |
| Cow manure | 1.64 |
| Horse manure | 1.97 |
| Sheep manure | 2.87 |
| Poultry manure | 4.00 |
| Weights of pig manure and horse manure added . . | 1.80 |

See also, U. S. Miscellaneous Report, Dep. Agr., Vol. 27, 1901, and Vol. 67, 1906.

This commercial evaluation, of course, must be applied with care because of the many factors tending to vary the composition of the excrement. *Litter*, particularly, will exert a great influence in this direction. Perhaps a safe figure as regards the commercial value of manure as it is likely to be handled on the average farm is about \$1.50 a ton. This approach more nearly the price that a market gardener, for example, may pay for such a product.

This commercial evaluation must never become confused with what is known as the *agronomical value* of a manure. The former is based on composition, while the latter arises from the effects so answered in crop growth. A manure of high commercial value may, when placed on the soil, yield only a low to medium agricultural return. This latter evaluation is, of course, the one of greatest significance in agricultural practice. A very good example of this might be cited from the Ohio experiments¹ with manure. In this case both treated and untreated manures were evaluated commercially and were then applied to the land. The value of the increased crops in a three-year² rotation was then calculated in terms of return to a ton of manure applied:—

COMMERCIAL AND AGRICULTURAL EVALUATION OF MANURES

| Manure | Commercial Per Ton | Agronomic Value, Per Ton |
|---|-----------------------|--------------------------------|
| Yard manure untreated | \$1.41 | \$2.15 |
| Yard manure plus bone | 1.66 | 1.21 |
| Yard manure plus acid phosphate | 1.65 | 1.07 |
| Yard manure plus lime | 1.65 | 0.79 |
| Yard manure plus gypsum | 1.48 | 0.78 |

¹ Thomas, C. R., and others. *The Measurement of Fertilizer* Ohio Agr. Exp. Sta., Bul. 102, pp. 595-596. 1902.

In practice, then, it is this epistemic limitation which must be especially violated. Its exposure should be not only in not yield to discovery, but also in not refuse to admit of access to itself.

48. The transformation of content¹—living, the processes of digestion the food of animals becomes more or less decomposed and dissolved. This condition comes about partly because of the digestive processes and partly from the bacterial action that takes place, largely in the lower intestines. Of these two influences within the animal, bacterial activities are probably of the greater importance so far as the breaking up of the complicated foodstuffs is concerned. The fresh excrement, then, as it comes from the stable, consists of dissolved or partially dissolved plant materials, with a certain amount of bacteria—dead animal tissue and mucus. This is now or has recently mixed with water and the whole mass is melted, or nutritional, with the liquid excrement, carrying, as it does, considerable quantities of soluble nitrogen and potash. This mass of material, ranging from the most complex compounds to the most simple, is brimming with bacteria, especially those that flourish in decay and putrefaction. The number very often runs into billions in a gram of excrement. In such an environment it is of little wonder that biological changes go on so rapidly.

Although in many different groups of organisms live and function in unison, and although in many products, both simple and complex, are continuously being split up, for maintenance and simplicity the bacteria may be

¹ Great discussion may be found as follows: HENRIOT, J. G. *Bacteria in Relation to Chemistry* 145, pp. 203-251. New York: Van. Nostrand & Co. Reinhold and Portland: pp. 105-204. New York, 1926.

grouped under two heads, aerobic and anaerobic. The former work in the presence of oxygen, the latter when air is either lacking or only very slightly present. This grouping is not a distinct one by any means, as many organisms may function not only in air but also when oxygen is lacking. The properties, however, are so different under these two conditions as if they were two distinct organisms.

446. Aerobic action.—When manure is first produced it is likely to be rather loose, and if allowed to dry at once it becomes well stirred. The first bacterial action is therefore likely to be rather largely aerobic in nature. Transformations are very rapid and are accompanied by considerable heat, ranging from 100° to 130° F. and sometimes higher. This action falls largely on the simple nitrogenous compounds. Thus, in practically all cases, and will very quickly disappear from well-aerated manure. The reaction is as follows:—



The ammonium carbonate is a volatile compound, and on the least exposure and evaporation of the material liquids it changes into ammonia and carbon dioxide. Thus nitrogen may be rapidly lost from manure by the action allowing of excessive aerobic decay and decomposition to proceed.

The simpler group of aerobic putrefactive organisms also attack to a certain extent the more complicated nitrogenous compounds, as well as some of the simpler carbohydrates contained in the solid and the liquid portions of the manure. These carbon dioxide therefore results, as well as certain simpler products which ultimately may be reduced to such a form as to be available as plant

food. In other words, the whole mass of the mixture tends to simpler forms. The mass becomes changed, waste is produced, and available plant-food is exhausted.

496. *Anaerobic action.* As the mixture becomes compacted, especially if it is left undisturbed, oxygen is gradually excluded within the heap and its place is taken by carbon dioxide, which is given off during the process of any form of bacterial activity. The fermentation now changes from aerobic to anaerobic, it becomes slower, and the temperature falls to as low as 30° or 35° F. New organisms may now flourish, and even some of the same ones that were active under aerobic conditions may continue to be effective. The process is now a deep-seated one and the products become changed to a considerable degree. Carbon dioxide, of course, continues to be evolved, but instead of ammonia being formed the nitrogenous matter is converted into the usual putrefactive products, such as indol, skatol, and the like. The carbonaceous matter is resolved into numerous hydrocarbons, of which methane (CH₄) is prominent; and as a by-product of the breaking-down of the proteins, hydrogen sulfide (H₂S) and sulfur dioxide (SO₂) are evolved. The complex nitrogenous and carbohydrate bodies are attacked with the splitting-off, not only of simpler materials, but also of those more complex. Such compounds may be listed in general as organic acids and lactic bodies. They of course ultimately succumb to simplification.

497. *Putrefaction in general.* In any process of decomposition, acids tend to form which if not neutralized will render the mass still more hostile to bacterial activity. This occurs when the soil becomes decomposed alone. The liquid masses, however, are alkaline and will tend to neutral any acidity due to fermentation. The above-

stage of either hauling the liquid and the solid together, or pumping the liquid over the solid at intervals, is thus free apparent.

The general changes in any muree pile can readily be recapitulated. First is the aerobic action, with escape of succinic and carbon dioxide. Next the muree is sealed, it compacts, and the slow, dependent decay sets in with a simplification of some compounds into the production of acids, and with a gradual formation of butyric acid. As the muree becomes alternately wet and dry, the two general processes may follow each other in rapid succession, the aerobic bacteria attacking the complex materials, the aerobic affecting both the complex and the simpler compounds. Carbon dioxide is given off continuously during the process.

396. *Gases from murees.*—The changes in the composition of the gases drawn from wet and compact murees, as compared with those from the same pile dry and open, are well shown from results by (Mehner):¹ The pile in this experiment was about eight feet high:

COMPOSITION OF GASES FROM DRY AND WET MUREES

| Muree | | Composition of | | | |
|-----------------------|--------|-----------------|----------------|-----------------|----------------|
| | | CO ₂ | O ₂ | CH ₄ | H ₂ |
| Dry muree | Top | 7.5 | 79.9 | 0.9 | 95.5 |
| | Middle | 14.5 | 4.7 | 1.3 | 79.5 |
| | Bottom | 86.8 | 0.0 | 0.2 | 0.1 |
| Wet and compact muree | Top | 12.7 | 1.1 | 82.4 | 3.8 |
| | Middle | 46.8 | 0.0 | 48.1 | 2.3 |
| | Bottom | 47.8 | 0.0 | 51.2 | 1.0 |

¹ *Bull. & U. Experiments and Monographs*, p. 188. New York: 1916.

It is noticeable that nitrogen seems to be lost under anaerobic conditions, but the production of methane is much increased. Carbon dioxide is present at all times.

46. *Change of bacterial composition of pitting mixture.*

— Because of the great loss of carbon dioxide during the fermentation process, there is a considerable change in bulk of the mixture. Fresh curdment loses 30 per cent in bulk by partial ritting, 40 per cent by more thorough ritting, and 60 per cent by becoming completely decomposed. This means that 1000 pounds of fresh mixture may be reduced to 800, 600, or 400 pounds, according to the degree of change it has undergone.

Although considerable loss of nitrogen may have occurred through simple bacterial action, and although both nitrogen and the mixture may have been considerably broken away, the loss of carbon dioxide is so much greater that generally there is an actual percentage increase of the former constituents in the well-ripped product. This relationship is well shown by figures from Yell¹ in which the samples were compared on the basis of equal amounts of dry matter:

COMPOSITION OF FRESH AND DECOMPOSED MIXTURES

| | Fresh (Per cent) | Decomposed (Per cent) |
|-------------------|---------------------|--------------------------|
| Alk. | 2.84 | 4.76 |
| Nitrogen | 0.20 | 0.49 |
| Clarks | 0.65 | 0.88 |
| Case | 0.60 | 0.61 |
| Phosphorus | 0.15 | 0.15 |
| Phosphoric acid | 0.96 | 0.92 |
| Hydrochloric acid | 0.10 | 0.13 |

¹ *Arkison, C. M. Mixture and Mixture, p. 288. (Hilf-Prop) and London, 1918.*

It need be remembered, however, that this is only a general case and holds good only when the nature has had fairly careful attention. When the nature has been improperly handled, the soluble constituents may be lost, as when no formal and a rotting product may result which is very low in nitrogen, potassium, and phosphorus. It is therefore evident that the handling of the fresh manure is a controlling factor in the ultimate value of the product.

A further insight into the condition of rotting manure is given by Webster,¹ the data being calculated on a dry-weight basis:—

| | Free ammonia (lb. per ton) | Ammonia nitrogen (lb. per ton) |
|-------------------------------------|----------------------------------|--------------------------------------|
| Stable organic matter | 7.15 | 11.0 |
| Stable inorganic matter | 4.55 | 5.98 |
| Unstable organic matter | 20.6 | 31.28 |
| Unstable inorganic matter | 11.96 | 27.52 |

These figures show the increased soluble matter in well decomposed manure and emphasize the value of rotting. The great loss of organic matter through the giving-off of carbon dioxide is also evident.

100. *Freezing of manure.*—A change of a frequent nature which sometimes takes place in loose and well-dried manure is freezing. Many farmers consider this to be due to actual combustion, as the manure is very light in weight and has every appearance of being burned. This condition, however, is produced by fungi (rot of bacteria) and the dry and dusty appearance of the

¹ Hedges, J. R. Soil Fertility and Fertilizers, p. 52. 2nd ed., Macmillan, 1902.

always is due to the spreading, which particulate is all dissolved and goes to the valuable constituents. Manure thus collected is of little value either as plant-food or as soil improver.

90. Waste of farm manure.—Any system of agriculture, in order to be permanent, must arrange for the addition of as much plant-food as is removed in the crop and the drainage water contained. Even if all of the crop were returned to the soil, a permanent system of agriculture would fall far short of being established, since at least as much plant-food is removed by leaching water carrying. As a matter of fact, it is not even possible to return to the land as farm manure all the constituents taken off in the crop, due to the excretion which heretofore. These losses may be grouped under two general heads: (1) those that occur as the food passes through the animal; and (2) those that are due to leaching and decomposition.

91. Losses due to digestion.—A certain quantity of material is necessarily taken from the original food as it passes through the animal. This loss falls most heavily on the organic matter and only slightly on the mineral constituents. *Willf*¹ presents the following figures averaged from all classes of animals:—

| PERCENTAGE OF NUTRIENTS FROM DIFFERENTLY KNOWN OR FROM 10000 | | | |
|---|---------------|-------------------|-------|
| | Food Eaten | Losses Mineral | Total |
| Organic matter . . . | 61.3 | 3.4 | 65.9 |
| Nitrogen | 66.1 | 17.3 | 83.5 |
| Mineral | 14.7 | 36.2 | 51.7 |

¹ *Willf*, C. M. *Manures and Manuring*, pp. 228 and 233. Edinburgh and London, 1918.

It is to be noted that the organic matter of the feed has retained an average loss of about 55 per cent, while the loss of nitrogen and of minerals has been 33 per cent and 2 per cent, respectively. The loss of the organic matter is especially serious, although it can be replaced by using green manures and the practicing of a proper rotation. The loss of nitrogen can be replaced only by the growing of legumes or by the addition of a nitrogenous fertilizer.

LOSSES due to leaching and fermentation. — In about one-half of the nitrogen and two-thirds of the potash in farm manure is in a soluble condition, the possibility of loss by leaching is very great, especially where the manure is exposed to heavy rainfall. The loss of phosphorus is also of some consequence. In addition, the fermentation, especially that of an acidic nature, will cause the formation of ammonia, which may be lost in large quantities if steps are not taken to control such action. It is evident that losses by leaching may be checked considerably by protecting the manure from excessive rainfall and by providing tight doors in the stable or an impervious bottom in the manure pit or under the manure pile. Packing and covering the manure will change the aerobic fermentation to anaerobic, thus reducing very markedly the production of ammonia while allowing a simplification of the chemical compounds to proceed steadily. All wise methods of handling and storing manure provide against those losses through leaching and fermentation by protecting the manure from rain and by controlling fermentation through moisture and aeration.

It is very difficult, in quoting figures for waste of manure, to separate the losses due to leaching from those due to fermentation. The two processes go on simulta-

quently, and the loss from one source is dependent, to a certain extent, on the other. It is only the nitrogen, however, that may be lost by both fermentation and leaching, the nitrate being nitrated only through the latter process. A few facts regarding the loss to nature when exposed to atmospheric conditions may not be amiss at this point:—

LOSSES FROM MANURES EXPOSED TO ATMOSPHERIC CONDITIONS

| | Manure | | Fertilizer | |
|------------------------------------|-------------------------|---------------------|-------------------------|---------------------|
| | Loss from Fertilizer | Loss from Manure | Loss from Fertilizer | Loss from Manure |
| Total of losses | 55 | 100 | 100 | 100 |
| Loss of nitrogen (per cent) | 55 | 100 | 100 | 100 |
| Loss of phosphoric acid (per cent) | 20 | 40 | 40 | 50 |
| Loss of potassium acid (per cent) | 40 | 42 | 42 | 48 |
| Loss of potash (per cent) | 60 | 75 | 75 | 85 |

It seems evident that when manure is exposed to atmospheric agencies, even under the best conditions, the losses of nitrogen, phosphoric acid, and potash will be on the average 55, 40, and 75 per cent, respectively.

¹Roberts, L. C., and Phipps, T. H. On the Determination of Fertilizer Manures by Land and Water Analysis. *Canada Dep. Agr. Rep. No. 10*, Vol. 13, 1880.

²Roberts, L. C., and Phipps, T. H. *Canada Dep. Agr. Rep. No. 10*, Vol. 13, 1880.

³Thomson, G. H. *Thomson's Manures*, p. 116, New York, 1864.

⁴Thomson, G. H., and others. *The Manufacture of Fertilizers*. *Canada Dep. Agr. Rep. No. 10*, Vol. 13, 1880.

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Under conditions on the average, then, such losses may easily rise to 50 per cent of all the constituents, and probably very much higher as regards nitrogen and potash. Foss's conclusion is three-fourths of the important elements contained in the original food falls to again much the same. Ball¹ (quoting from Woods' experiments at Cambridge, shows that about 10 per cent of the nitrogen in the food consumed is retained by the animal. He also shows that 15 per cent of nitrogen is lost during the mauling, and from 10 to 25 per cent during the storage of the manure, even under the best conditions. This gives a total loss of nitrogen amounting to from 35 to 50 per cent. If this is the loss under the best conditions, it can readily be seen that the loss on an average must approach 65 or 75 per cent.

Since there is so gigantic losses from fermentation and leaching may be gained from this, does it not cause? In this experiment a mixture of horse dung and manure was divided. One half was placed in a bin under a shed; the other half was exposed to the weather, outside in a similar bin. After a year the two portions were analyzed and the losses computed:

LOSSES FROM MANURE LEACHING THROUGH WATERS

| | Potash (lb. per ton) | Ammonia (lb. per ton) |
|-----------------------------------|-------------------------|--------------------------|
| Loss of organic matter | 80 | 49 |
| Loss of nitrogen | 25 | 48 |
| Loss of phosphoric acid | 4 | 15 |
| Loss of potash | 2 | 30 |

¹ Hall, A. D. *Fertilizers and Manures*, p. 195. New York: 1901.

² Robert, H. A. *Fertilized Manure*. Canadian Dept. Agr. Chem. Rep. Farm, Oct. 21, 1898.

Further the losses by leprosatolins are very considerably augmented by exposure, especially if the rainfall is high. This point not only is very considerable as regards the damages, but is especially high as far as the economic matter is concerned. Such figures serve also to explain again the importance of diluting manure is always more expensive than diluting. Since water is, of course, necessary, but too much serves only to carry away the nutrients already soluble or rendered soluble by leprosatolins.

RM. Increased value of provincial manure.—From the previous discussion it is evident that a well-ventilated and carefully preserved manure will be higher in plant-food constituents than one not so handled. Moreover, the agricultural value of such manure will be higher. This is shown by actual tests from Ohio: Over a period of fourteen years, in a three-year rotation of corn, wheat, and hay, a small manure gave a yield 10 per cent higher than that with a good manure, the quantities applied in each case being equal. In New Jersey, in comparing fresh manure with leached manure the former showed a gain in crop yield 50 per cent higher than the latter over a period of three years immediately following the application. Such figures are worthy of careful consideration by the average farmer.

RM. The money waste of manure.—To make the recurrence of the question of waste in various forms striking, the probable losses may be tabulated in money value for the United States. The entire live stock of all kinds in this country may be roughly estimated to require

¹Thorne, C. D., and others: *Manure and Germany Values of the Manure of the United States*. (New York, New York, 1912).

plant in maize producing capacity to about 100,000,000 cattle, each weighing 1000 pounds. Assuming that each animal will produce manure to the value of \$2 a year and that the cattle are period for four months, the total value of excrement produced during the yearling period would be, in round numbers, \$800,000,000. If only one-third of the value of the manure is lost by mis-handling, an annual waste of \$253,000,000 would occur. This is a very conservative estimate regarding the loss of farm manure throughout the United States. The annual sale of commercial fertilizers in this country, probably amounting to over \$100,000,000, is entirely inadequate to replace this loss.

66. Handling of manure.¹—The ultimate consideration in a study of farm manure comprises the best methods of excrement handling, both as to where and as to the timing of the excrement returned by the product. The greater the amount of plant-food that can be stored in the manure and returned to the land, the less will be the necessity of commercial sources of these elements. Many methods present themselves as being more or less efficient, but none are absolutely perfect, as losses by fermentation are bound to occur even though leaching is entirely prevented. Methods of handling are usually chosen because of their adaptability to particular circumstances, rather than because of the exact amount of valuable constituents that they will conserve.

¹ Good discussions of handling farm manure are as follows: Hays, S. E. *Getting the Most Profit from Farm Manure*. Vineland, N. J.: The Soil, 1913. 162 p. 1000 V. 2. 1000 yard Manure. U. S. D. A., Farmers' Bldg. 110. 1904. 16 pages. 1. P. The Fertility of the Land, Chapter IX, pp. 186-223. New York. 1884.

57. Care of manure in the stable.—Considerable loss of manure occurs in the stable, due to fermentation and leaching. Before the litter can absorb the liquid, it is likely to ferment and to leak away in superficial currents. Therefore the first care is as to bedding, which should be chosen for its absorptive properties, its cost, and its cleanliness. The following table¹ expresses the absorptive capacity of some common litters:

ABSORPTIVE POWER OF SEVERAL KINDS OF LITTER

| | Pounds |
|---------------------------------|--------|
| Wheat straw | 220 |
| Dark leaves | 195 |
| Pine | 160 |
| Sawdust | 45 |
| Spirit turp | 45 |
| Air-dry horse-sawdust | 50 |
| Dry good manure | 130 |
| Muck | 200 |

The amount of litter to be used is determined by the character of the food. If the food is watery, the bedding should be increased. In general, the litter may amount to about one-third of the dry matter of the food consumed. Sheep require about a pound of bedding a head, cattle from eight to ten pounds, and horses from six to seven pounds. No more litter than is necessary to keep the animal clean and to absorb the liquid manure should be used, as the manure is thus diluted unnecessarily with material which often does not carry large quantities of fertilizing ingredients.

¹ See, W. E. Howard Moore, U. S. D. A., Farmer's Bul. 117, 1906.

The next one is that there shall be light, so that the liquids cannot drain away but will be held in contact with the absorbing materials. The preserving of carcasses in stalls with tight floors has been for years a serious method of handling dung in England. The tramping of the animal and the continued addition of litter with the liquid and solid excrement, explain the reason for the success of the method. The following data, from Olney show the relative recovery of food elements in manure produced on a cement floor and on an earth floor, respectively. The experiment was conducted with sheep over a period of six months.

TABLE SHOWING THE RESULTS OF AN EXPERIMENT ON THE RECOVERY OF FOOD ELEMENTS IN MANURE PRODUCED ON A CEMENT FLOOR, ON A EARTH FLOOR

| | Per Cent | Per Cent |
|----------------------|----------|----------|
| Nitrogen | 74.7 | 62.4 |
| Phosphorus | 77.5 | 52.8 |
| Potash | 87.8 | 73.4 |

398. *Feeding directly to the field.*—Where it is possible to feed directly to the field, this practice is to be advised, since opportunities for extensive losses by tramping and fermentation are thereby prevented. Manure may even be spread on frozen ground or on the top of snow, provided the land is fairly level and the snow is not too deep. This system saves time and labor, and when feeding does occur the valuable portions of the manure are carried directly into the soil.

399. *Compost pit.*—Very often it is not convenient

*Patten, C. E. *The Maintenance of Fertility*. 1904
Ag. Exp. Sta. Bul. 385, p. 193. R.H.C.

are possible, especially in certain parts of the year, to haul manure directly to the field. Means of storage must therefore be provided. Some farmers if the amount of manure produced on their farms is large, find it profitable to construct manure pits of concrete. These storage pits are usually rectangular in shape, with a shed covering, and with open ends so that a team may drive in and out at the ends. In such a pit loading is prevented by the covering and by the solid bottom. By keeping the manure carefully spread and well covered, fermentation may proceed with a minimum loss of nitrogen. Some farmers even go so far as to add a current, into which is absorbed both the liquid and the solid manure. Later, when fermentation has proceeded sufficiently, the material is pumped out and applied to the land. This method is not to be advocated in this country except under particular conditions.

230. *General barnyard*.—Another method of storage is by means of a covered barnyard. Such a yard must have an impervious bottom. The manure is spread out in the yard, and if animals are allowed to exercise here the manure is kept thoroughly packed as well as damp. The storage of manure in deep stails, a favorite method in England, is similar to this system and has been shown to be very economical. It also affords an opportunity for the mixing of the manure from different classes of animals. The desirability of this has already been shown regarding horse and cow excrements. The advantages of compaction, so far as the keeping qualities of manure are concerned, are clearly shown by the following figures taken from the work of Peart:¹—

¹Peart, W. *Science of Manure*. Philadelphia: Jpn. Exp. Sta., 1911, 63, 292.

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Loss of Moisture in Covered Bins

| | Percentage of | | |
|--------------------------|---------------|------|------|
| | W | EO | MO |
| Corn and sorghum | 5.1 | 5.5 | 8.5 |
| Corn and oats | 10.1 | 10.0 | 10.5 |

Throwing masses in heaps under a shed and allowing hops to walk the mass over, is an economical practice so far as food utilization is concerned. It interferes, however, with proper and economical picking of the masses. The question is to be decided whether the added food value of the masses outweighs the loss, caused by fermentation incurred by the heating of the silage.

614. *Flare outside.*—Very often it is necessary to store masses outside, fully exposed to the weather. When this is the case, certain precautions must be observed. In the first place, the pile should be located on level ground far enough from any building so that it receives no rain water (down in lanes of storm). The earth under the pile should be slightly raised in order to prevent loss of excess water. If possible, the soil of the depression should be puddled, or better, lined with cement.

The sides of the heap should be perpendicular, so as to shed water readily. The masses must be kept moist in dry weather in order to decrease aerobic action. Each addition of masses should be packed in place, the fresh one used where the older. This allows the carbon dioxide from the well-cooled dung to permeate the fresher and better portions, thus quickly establishing the anaerobic

conditions as essential to economic and favorable fertilization.

Placing fresh manure in small heaps in the field to be spread later, is, in the first place, poor economy of labor. Moreover, it wastes gas by fermentation, while at the same time the volatile portions of the pile escape into the soil immediately underneath. There is thus a poor distribution of the essential elements of the dung, and when the manure is finally spread, an overloading of plants at one point and an underfeeding at another results. A low efficiency of the manure is thus realized. This method of handling manure is not to be recommended.

III. *Distribution of manure in the field.*—In the actual application of manure to the land, certain general principles should always be kept in mind. In the first place, evenness of distribution is to be desired, since it tends to raise the efficiency of the manure by securing a more uniform plant growth. This evenness of spreading is much aided by division of manure. Moreover, it is generally better, especially in divided farming on medium to heavy soils, to decrease the amounts at each manuring and apply oftener. Thus, instead of adding 20 tons to the acre, 10 tons would be applied and twice as much once covered. The applications would then be made oftener. A larger and quicker return is not only paid per ton of manure applied, would be realized. This has been strikingly shown by the Ohio experiments¹ over a test for eighteen years in a three-year rotation of wheat, clover, and potatoes, the manure being placed on the wheat and affecting the clover and the potatoes in a

¹Thomas, C. B., and others: *Thaps and Stearns Studies of the Hypothesis of the Central Farm*. Ohio Agr. Exp. Sta., Circ. 120, p. 106, 1902.

prudence. The results are expressed in bushels per ton of manure applied:—

YIELD OF THE POT IN HUMAN MANURE APPLIED IN
DIFFERENT QUANTITIES

| | Manure (Bushels) | Crop (Bushels) | Manure (Bushels) |
|-----------------------------|---------------------|-------------------|---------------------|
| 4 tons to the acre | 20 | 27 | 27.3 |
| 8 tons to the acre | 41 | 100 | 24.4 |
| 16 tons to the acre | 24 | 99 | 11.6 |

Not only is the increased efficiency from horse applications apparent, but a great recovery of the manure's fertility in the crop also results. The Ohio experiments have shown that in the first rotation after the manure is applied, a recovery may be expected from a treatment of 8 tons 15 to 20 per cent higher than from one of 16 tons.

Processes of application and measures of division are greatly facilitated by the use of a manure spreader. This also makes possible the uniform application of small amounts of manure, even as low as five or six tons to the acre. It is impossible to spread so small an amount by hand and obtain an even distribution. Moreover, a spreader saves the labor and time that double the amount of manure one man can apply a day. When any quantity of manure is to be handled, a manure spreader will pay for itself in a season or two at the most.

Whether manure should be plowed under or not depends largely on the crop to which it is used. On timothy it is spread as a top-dressing. Definitely, however, it is plowed under. This is particularly necessary if the

manure is large, coarse, and not well sorted. It should not be turned under early, however, as to prevent ready decay. If manure is fine and well decomposed, it may be harrowed into the surface soil. The method employed depends on the crop, the soil, and the condition of the manure. This amount to be applied varies considerably. Eight tons to the acre would be a light dressing, 15 tons a medium dressing, and 25 tons heavy for an ordinary soil. On trading lands, however, as high as 30 or 100 tons is often used.

III. Reinforcement of manure.—The reinforcement of farm manures is designed to accomplish two things in the feeding of the product: (1) checking too rapid fermentation, and (2) holding the manure and rendering its agricultural value higher. Four chemicals may be used in this reinforcement: gypsum (CaSO_4), kaint (KCl , usually), acid phosphate ($[\text{CaH}_2(\text{PO}_4)_2 + \text{CaH}_2\text{O}]$), and feats (pure rock phosphate, $\text{Ca}_3(\text{PO}_4)_2$).

Gypsum is supposed to act on the ammonia, changing it to ammonium sulfate, a stable compound. It is rather insoluble, however, so that its action is slow. It may be applied in the stable or on the manure pile. The rate is about 100 pounds to the ton of manure. It has no balancing effect.

Kaint is added to manure with any ammonia that may be produced and also to increase the potash in the manure. It is soluble, and because of its caustic tendency it must not come into contact with the feet of the animals. It must not be ground on the manure, therefore, until the stock has been removed. Since manure is unbalanced as to phosphorus, the agricultural value of it is increased when it is light. Kaint is usually added at the rate of 50 pounds to the ton of manure.

Acid phosphate, when used as a reinforcing agent, is applied at the rate of 50 pounds to the ton of manure. It is soluble, and therefore becomes intimately mixed with the current. It adds phosphate, in which manure is especially lacking. Its presence may react with the manure. Theoretically it should prevent loss by fermentation, as well as function as a leaching agent. It must not come into contact with the feet of farm animals.

Rose rock phosphate, or fluo, is a very insoluble compound, and consequently reacts but slowly with the soluble constituents of manure. Carrying such a large percentage of phosphate, it tends to balance the product out to near its agricultural value. It is supposed that the intimate relationship between the phosphate and the decaying manure increases the availability of the former to plants when the mixture is added to the soil. No increased solubility, however, as determined by chemical means, has ever been as definitely shown to occur (see par. 428). The reinforcement is usually at the rate of 100 pounds to the ton of manure.

III. Results from reinforcing.—Experimental data have shown that these various reinforcements have no effect on the nature, function, and number of the bacterial flora. Their conserving influence, if any, when the manure is exposed, must be in checking leaching and in preventing loss of manure. The following figures from Ohio experiments¹ show how slight this conserving effect is. The reinforcement was at the rate of 10 pounds to the ton:—

¹Thomson, C. R. *Maintenance of Fertility*. Ohio Agr. Exp. Sta., Bul. 335, p. 209, 1907.

QUANTITATIVE STUDY OF REGENERATING ACTION ON MANURE
FURNISHED FOR FRUIT MATTERS

| Treatments | Yield of a Plot of Cabbage | | Percentage of Loss |
|--------------------------|-------------------------------|----------|-----------------------|
| | 1st Year | 2nd Year | |
| No treatment | \$2.29 | \$1.41 | 38 |
| Optimum | 2.25 | 1.45 | 36 |
| Stable | 2.24 | 1.45 | 35 |
| Wash | 2.25 | 1.45 | 34 |
| Acid phosphate | 2.24 | 1.45 | 33 |

It is immediately evident that basal and gypsum do not conserve the manure, and, although acid phosphate and lime show some influence, it is slight. The principal benefit from manuring manure, if any, must therefore be as a bulking agent. The figures from 1916, over a period of fourteen years in a rotation of corn, wheat, and soy, may be taken as evidence regarding this point. The manure was added to the corn at the rate of 5 tons to the acre. The following was 40 pounds to the ton of manure in every case:—

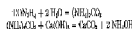
THE REGENERATION OF FRUIT MATTERS

| Treatments | Yield of a Plot of Cabbage | | Percentage of Loss |
|--------------------------------------|-------------------------------|----------|-----------------------|
| | 1st Year | 2nd Year | |
| Manure plus lime | \$15.04 | \$4.41 | |
| Manure plus acid phosphate | 15.04 | 4.82 | |
| Manure plus 1916 | 20.07 | 4.71 | |
| Manure plus gypsum | 20.06 | 5.03 | |
| Manure alone | 20.06 | 5.21 | |

Wheeler, C. R., and others: *Manure and Fertilizer Values of the Republics of the Central States*. Ohio Agr. Exp. Sta., Cir. 246, p. 125, 1915.

This balancing effect may be shown in another way. Let it be supposed that 10 pounds of poultry manure, having a composition of 1.6 per cent nitrogen, 1.8 per cent phosphoric acid, and 0.9 per cent potash, there are added 4 pounds of manure, 4 pounds of acid phosphate, and 2 pounds of kiesel. The manure is rendered dirty, and its composition becomes 0.8 per cent nitrogen, 2.7 per cent phosphoric acid, and 1.5 per cent potash. It is evident, from this and the data previously given, that the principal benefit of manuring manure lies in the balancing influence, and that acid phosphate and kiesel are the most desirable to use.

Ask lime and manure. — Very often it would be a saving of labor to apply lime and manure to the soil at the same time. This can readily be done with the mechanical farms. Such lime may be mixed with the manure, either in the stable or in the pile, without any danger of detrimental results. The close action of the lime and the organic matter may even increase the solubility of the former. Certain compounds of lime, however (CaO and Ca(OH)_2), must be kept from manure. These active forms react with the ammonia contained coming from the urine, and cause the liberation of the ammonia, which may be readily lost in the air:—



A stable or a shed containing manure may be at once disinfected by the use of quicklime, but only by the loss of much nitrogen, which acts on the market eighteen or twenty cents a pound. Caustic lime and manure may be applied to the manure and by applying the lime ten days or two weeks before the manure. The lime will then

have had time to *leach* into the soil or to largely change to a *carbonate form*.

21st. Composting.—A compost is usually made up of alternate layers of manure and some vegetable matter that is to be decayed. Layers of soil or of house soil are often introduced. The manure is used to supply the decay organisms and to start the action. The breakdown of such a house manure is usually not, and the pile is preferably covered with earth. The compost should be kept moist in order to prevent loss of ammonia and to encourage vigorous bacterial action. Acid phosphates or raw rock phosphates and a potassium fertilizer are often added, to balance up the calcium and make it more effective fertilizer. Lime is also placed over, covered with such organic acids as may lead to form and to interfere with proper decay. Unkempt plant stumps, such as soil, leaves, weeds, grass, stubble, or organic refuse of any kind, may thus be changed slowly to a house which will be suitable in building up the soil and in revivifying plants. Best results may be obtained if in such a manner.

22d. Manure and man.—Bogk soil recently as obtained from a cessary resolution is usually treated, if possible, with a dressing of manure. This is not so much for the purpose of adding phosphorus as to supply decay and decomposition organisms that will break down the complicated basic compounds into such forms as may be utilized by the crop. Plenty of lime is therefore essential to work, in order to render the effects of this manure effective and lasting.

23d. Effects of manure on the soil.—The direct fertilizing effect of manure is by no means its greatest influence. In the first place, manure as it enters does produce humus. This humus increases the absorptive

capacity of the soil. In clay χ promotes granulation, while in sands it acts as a binding agent. Under all conditions it promotes granulation and tilth. The capacity of a soil to resist drought is raised; its aeration is increased and drainage is promoted. All these changes tend to benefit plant growth and to produce those indirect fertilizing effects that are characteristic of farm manure.

From the chemical standpoint, the presence of manure in the soil tends to increase organic acids, notably carbonic acid. The soil absorbs the thus rendered more easily soluble. The case of the influence of manure on the action of any rock in the soil has already been cited. The humus, also, may combine with certain of the mineral elements and hold them in a form more easily available to crops. Much of the chemical influence of farm manure is the final effect. The modification of the soil here may by no means be passed by. Not only are millions of organisms added by an application of manure, but those already present in the soil are greatly stimulated by this fresh acquisition of basic materials. Nitritation, nitrification, and nitrogen fixation are all increased to a remarkable degree.

13. *Residual effect of manure.*—No other fertilizer material exerts such a marked residual effect as does manure. This is partly because of its indirect physical and biological influences, and partly because of the stimulated root development of the crops grown. The greatest residual influence, however, is brought about by the slowly decomposable nature of the manure, only a small percentage being removed in the first crop grown after the manure is applied. Hall¹ presents the following data:

¹ Hall, A. D. *Fertilizers and Manure*, p. 243. New York, 1906.

just demonstrated. The crop was miserable, and the necessity of the continuous sowing by the farmers was very large.

REVENUE OF MANURE IN A CASE OF MANURE

| Manure | No. tons | Yield in Tons | Estimated Revenue |
|----------------------|-------------|------------------|----------------------|
| Manure of muck . . . | 500 pounds | 17.45 | 79.1 |
| Ammoniacal muck . . | 500 pounds | 15.52 | 52.2 |
| Superphosphate . . . | 2500 pounds | 26.35 | 70.8 |
| Manure | 14 tons | 17.44 | 31.8 |

The length of time through which the effects of an application of farm manure may be detected in crop growth is very great. Hall¹ cites data from the United States experiments in which the effects of eight yearly applications of 16 tons each were apparent forty years after the last treatment. This is an extreme case; ordinarily, profitable increases may be obtained from manure only from two to five years after the treatment. The fact remains, nevertheless, that of all fertilizers farm manure is the most lasting, both the most valuable to the soil, and is truly a soil builder per se.

520. Place of manure in the rotation.—With a number of trucking crops, the application of manure directly to the crop year after year has proved to be advisable. In an ordinary rotation, however, where less intensive methods are employed, it is evident that manure may vary in its effect according to the place in the rotation at

¹Hall, A. D., *Fertilizers and Manure*, p. 113. New York, 1898.

which it is applied. This has proved to be the case with commercial fertilizers, and the fact is also becoming recognized in the economic use of farm manures.

In general, hay has derived more benefit from the residual food than almost any other crop in the rotation. At the Pennsylvania Experiment Station² in a rotation of oats, wheat, and hay over a test for twenty-five years, in which manure was applied in equal amounts to the oat and wheat, the results were as follows:—

²⁷
PERMANENT EXPERIMENT WITH OATS AT MANASSAS, AND VALUE OF
THEY INCREASED

| Treatment | Oats | Oats | Wheat | Hay |
|--------------|-------------|-------------|-------------|-------------|
| Clear manure | 27 per cent | 26 per cent | 77 per cent | 23 per cent |
| Cost \$0 | \$1.35 | \$1.10 | \$2.70 | \$1.14 |

The same fact has been clearly shown in the Ohio experiments³ covering a term of eighteen years. The query immediately arising here is: If hay responds as well to residual feeding, why not apply the manure directly to it? On this point the following figures from the Illinois Experiment Station⁴ may be presented, comparing the response of oats and oats when manured to the yield of clover with the same treatment:—

¹ Hunt, C. F. *Greenhouse Fertilizer Experiments*. Ann. Rept. Pennsylvania Agr. Exp. Sta., 1897-1898, pp. 48-56.

² Wilson, C. B., and others. *Manure and Fumigant Value of the Experimentum in the Central Farm*. Ohio Agr. Exp. Sta., Cir. 122, pp. 104-106, 1905.

³ Dapkins, R. B. *Thirty Years of Crop Rotation in Illinois*. Ill. Agr. Exp. Sta., Bul. 115, p. 227, 1903.

| Fertilizer | Ultimate Percentage Returns | | Total Return per Acre | |
|--|-----------------------------|------|-----------------------|-------|
| | Grain Crop | Crop | Grain Crop | Crop |
| Manure | 11 | 39 | 5.742 | 8.046 |
| Manure, straw and plaster | 18 | 41 | 10.62 | 11.96 |

When hay is included in any rotation it is evident that the best results from manure may be obtained by plowing it on this crop. This, however, is often not advisable, especially where the amount of manure is limited. A conventional fertilizer may take its place on the hay, allowing the farm manure to be utilized on special crops. When applied to hay it should be turned on a light top dressing.

When manure is used for such a crop as corn, however, it is best plowed under, as the manure will per se be of little value. Farm manure in plowland manure may be harrowed or plowed under in advance.

352. *Remarks.*—From the general discussion already presented, it is evident that harrowed manure, from the standpoint of soil fertility, is the most valuable by-product of the farm. A careful farmer will therefore attempt to utilize it in the most economical way. The handling of manure is such a matter that only a small waste will occur from the time when the manure is added until it has reached the land again, is not an easy problem. Manure is so susceptible to the loss of valuable constituents both by leaching and by fermentation that special methods must be employed. The utilization of light frosts in the stable yard of removed manure crops is to be de-

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view. Flushing immediately to the field is a wise procedure. Yet even with the best of care a loss of from 10 to 50 per cent is often incurred. A permanent system of agriculture evidently cannot be established by simply returning all the manure possible to the land. Nevertheless, it is certainly worth the while of any farmer to use at least some care in the handling of this product. Some reasonable attention could save for the soils of this country thousands of dollars' worth of manure and fertility which is now carried away in the streams and rivers.

CHAPTER XXVI

GREEN MANURES

How time immemorial the turning-under of a green crop to supply organic matter to the soil has been a common agricultural practice. Records show that the use of beans, vetches, and lupines for such a purpose was well understood by the Romans, who probably imported the practice from nations of still greater antiquity. The art was lost to a great extent during the Dark Ages, but was revived again as the modern era was approached. At the present time green-manuring is considered a part of a well-established system of soil management, and is given a place, where possible, in every rational plan for permanent soil improvement.

262. Effects of green manuring.—The effects of turning under green plants are both direct and indirect, direct as to the influence on the succeeding crop, and indirect as to the action on the physical condition of the soil so treated. In the first place, certain ingredients are actually added to the soil by such a procedure. The carbon, oxygen, and hydrogen of a plant come largely from

¹Parry, C. I., *Power Crops as Green Manures*. Oklahoma Agr. Expt. Sta., Bul. 11. 1905.
Stear, P. H. *Agriculture*, pp. 137-138. New York. 1903.
Lippens, J. O. *Experiments in Rotation to Grow Hay*, Chapter XXVI, pp. 227-240. New York. 1911.
Perry, C. I. *Leguminous Crops for Green Manuring*, P. 8 D. A., *Harvesters' Bul.* No. 224. 1907.
Hullgren, W. J. *Harvesters' Bul.* No. 225. (S. R. D. A., *Harvesters' Bul.* No. 225. 1908.)

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the air, and the plowing under of a crop therefore increases the store of such constituents in the soil. If the plant is a legume and the nodules organisms are active, the nitrogen content of the soil is also augmented. The mineral parts of the humus-water crop, of course, come from the soil originally and they are merely turned back to it again. As they return, however, they are in intimate union with organic materials, and are thus readily available as plant-food as the decay process goes on. Indeed they are much more readily available than they previously were, when the green-manuring crop supported them. Actual additions are thus made to the soil, together with a provision of an increased availability of the mineral salts itself with.

Green manures may function also as cover crops, in so far as they take up the extremely soluble phosphate and prevent it from being lost in the drainage water. The nitrate of the soil are of particular importance in this regard, as they are very soluble and are washed out slightly by the subsoil water. Besides this, green manures, especially those with long roots, tend to carry food up from the subsoil, and when the crop is turned under this material is deposited within the root zone. Again, the added organic material acts as a food for bacteria, and tends to stimulate biological changes to a marked degree. This bacterial action is especially prone to increase the production of carbon dioxide, ammonia, vitamin, and organic acids of various kinds, which are very important in plant nutrition. The humus that results from this decay increases the adsorptive power of the soil and promotes aeration, drainage, and penetration — conditions that are extremely important in successful crop growth.

338. *Quantities of plant constituents added by green-mustering*.—In an average crop of green manure, from five to ten tons of material is turned under. If this, then, runs to two tons is dry matter, and hence four to eight tons water. Of this dry matter a great proportion is carbon, hydrogen, and oxygen—a clear gain to the soil in so far as these constituents are concerned. The amount of nitrogen added to a soil if the green manure is a legume¹ is a difficult question to decide. Much depends on the microbes of the organisms occupying the nodules. These bacteria are in turn much influenced by plant and soil conditions. Haglin² estimates that about one-third of the nitrogen in a normal inoculated legume comes from the soil and two-thirds from the air. He also considers that one-third of the nitrogen exists in the roots. It is evident, therefore, that in general the nitrogen found in the tops will be a rough measure of the nitrogen fixed by the plant organisms. If this is returned to the soil, there is a clear gain of just that amount.

If the preceding assumption is correct, clover³ would actually add to every acre about 40 pounds of nitrogen

¹ Farley, C. T., and Robinson, F. W. Influence of Nodules on the Growth of the Underground of Soybean and Cowpea. *Miss. Agr. Exp. Sta., Bul.* 256, 1904.

² Haglin, C. E. *Methods on Illinois Soil.* Illinois Agr. Exp. Sta., Bul. 28, 1902.

³ Haglin, C. E. *Nitrogen Bacteria and Legumes.* Illinois Agr. Exp. Sta., Bul. 34, 1902.

⁴ Ward, P. P. The Nitrogen Requirement of Soils through the Growth of Legumes. *Canadian Dept. Agr. (Biol. Chem. Div.)* *Bull.* 1904, pp. 127-132.

⁵ Haglin, C. E. Soil Fertility and Permanent Agriculture, p. 235. (Boston, 1901).

⁶ Conner, C. L. The Growth of Common Clover. *Illinois Agr. Exp. Sta., Bul.* 27, 1906.

per ton, 180 lbs. about 50, compare C5, and say leave 15 pounds. These figures, even though they may be far from correct, at least give some idea as to the possible addition of nitrogen by green-manuring practices, and show how the soil may be enriched by such management. As in the case of farm manures, the indirect effects of such a procedure may outweigh the direct influences, making the use of legumes as green-manuring crop less necessary than at first thought might be supposed.

120. Decay of green manure.—As a green crop enters the soil, the process of its decay is the same as that of any plant tissue that becomes a part of the soil body. The organisms that are active are those common to the soil, together with such factors as are carried into the soil on the green-rotting crop. The decay should be accelerated under suitable conditions so that only beneficial products may result. Firstly of water is a necessity, as otherwise the soil would be robbed of a part of its available moisture in hastening the process of decay. When proper decay has occurred, end products should result which can be utilized as plant-food. The intermediate compounds that are formed should yield a black humus, should readily split up into simple compounds and should be in general beneficial, both directly and indirectly, to crop growth. The decay of green manure under conditions of poor drainage and laggy soil is likely to cause the production of materials detrimental to the proper development of plants.

121. Crops suitable for green manure.—The crops that may be utilized as green manures are usually grouped under two heads, legumes and non-legumes. Some of the common green manures are as follows:—

| Legumes | | Non-legumes |
|------------------|----------------|-------------|
| Annual | Perennial | |
| Compost | Red clover | Rye |
| Soy beans | White clover | Oats |
| Timothy | Alfalfa clover | Kentucky |
| Vetch | Alfalfa | Wheat |
| Canada field pea | Stem clover | Buckwheat |
| Winter vetch | | |
| Crabgrass clover | | |
| Timothy vetch | | |

When other conditions are equal, it is of course always better to choose a leguminous grass mixture in preference to a non-leguminous one, because of the nitrogen that may be added to the soil. However, it is no often difficult to obtain a catch of some of the legumes that it is poor management to turn the plow under well after a number of years. Despite the fact that many legumes are very expensive, almost prohibitive their use as green manures. Among the legumes most commonly grown as green manures, cowpeas, soy beans, and peanuts may be named. Many of the other legumes do not so fit into the common rotations as to be readily turned under as a green manure.

For the reasons already cited, the non-legumes have in many cases proved the more popular and economic as green manures. Rye and oats are much used because of their rapid, abundant, and succulent growth and because they may be accommodated to almost any kind of a soil level. They are thus generally valuable on poor soils. Often the value of such a green manure is only in part increased by sowing peas with it. The advantages of a legume and a non-legume are thus combined.

618. When to use green manures. The indefinite rate use of green manures is of course never to be advised, as the soil may be injured directly and the normal rotation much interfered with. When soils are poor in nitrogen and humus, they are very often in poor tilth. This is true whether the texture of the soil be fine or coarse. The turning under of green crops must be judicious, however, in order that the soil may not be clogged with undrained matter. Once or twice in a rotation is usually often enough for such treatments. Proper drainage must always be provided. In regions where the rainfall is scanty, very great caution must be observed in the handling of green manures. The available moisture that should go to the succeeding crop may be used in the process of decay, and the soil left light and open, due to an excess of undecomposed plant tissue.

619. When to turn under green crops.— It is generally best to turn under green crops when their succulence is near the maximum. In this case a large quantity of water is carried into the soil, and the drain on the original soil moisture is less. Again, the succulence encourages a rapid and more or less complete decay, with the maximum production of humus and products. The plowing should be done, if possible, at a season when a plentiful supply of rain occurs. The effectiveness of the manuring is thereby much enhanced.

620. How to turn under green material.— In general, in turning under green manures the furrow slice should not be thrown over flat, since the green crop is then deposited as a continuous layer between the surface soil and the subsoil. Capillary movement is thus impeded until a more or less complete decay has occurred, and the succeeding crop may suffer from lack of moisture.

The furrow ordinarily should be turned only partly over, and driven against and on its neighbor. The green manure is then distributed evenly from the surface downward to the bottom of the furrow. When decomposition occurs the humic materials are evenly mixed with the whole furrow slice. Moreover, this method of plowing does not interfere with the regular movements of water, and in actual practice is a great aid in drainage and aeration.

329. Green manures and flow. — The decay of organic matter in the soil is always accompanied by the production of organic acids. Such acids tend to form in large amount, especially if the fermenting matter is of a molecular nature. The need of plenty of lime under such conditions is clearly apparent, as a soil of a neutral or an acid character may assume a bad condition during the process of humus decay. Lime may be added to the green-manure seedling and be turned under with that crop. The neutralized soil thus be in very close contact with the decaying vegetable tissue. Ordinarily, however, the application of lime at some point in the rotation is sufficient.

330. Green manure and the rotation. — Very often it is somewhat of a problem as to what, in an ordinary rotation, a green manure may be introduced so that it may fit in well with the crops grown. In a rotation of corn, oats, wheat, and two years of hay, a green manure might be introduced after the oats. This would not be a very good practice, however, as a cultivated crop should usually follow a green manure so as to facilitate decomposition and decay. In such a rotation the plowing under of the hay stubble is really a form of green-manuring, there being a considerable accumulation of roots,

stable, and abundant on the soil. When a rotation of this kind is used it is better either to supply organic matter to other crops, or to alter or break the rotation in such a manner as to admit of a more advantageous use of green crops.

When feeding crops are grown and no very definite rotation is adhered to, green-manuring is easier. It is especially facilitated when cover crops are grown, as is certainly. Sifting operations also favor the easy and profitable use of green manures. In general it may be said that the organic matter obtained from such a source should be supplemented by farmyard manure where possible. A better balance and richer soil texture is more likely to result.

CHAPTER XXVIII

LAND DRAINAGE

Land drainage¹ is the process of withdrawing from the soil the superfluous or prejudicial water occurring in the larger spaces within the natural soil mass. Water moisture in the soil interferes with ventilation, keeps down the temperature, and seriously disturbs the physical nature of the soil. Any excess that remains the free flow from the soil to the point of disposal is called drainage. Many methods are used, according to circumstances. Indications of the need of drainage are the presence of free water in the surface soil and its excretion into the

¹Blair, C. G. *Engineering for Land Reclamation*. New York, 1912.

Barre, L. *Drainage et Amélioration Agricole des Terres*. Paris, 1875.

Gray, P. B. *Irrigation and Drainage*, Part II. New York: Plenum, 1961.

Harwood, J. B. *Practical and Theoretical of Land Drainage*. Cincinnati, 1904.

Woodward, S. M. *Land Drainage by Means of Pumps*. U. S. G. P., *Water Res. Div.*, Bul. No. 915, 1911.

Waters, G. M. *Water, Moisture and their Reactions*. U. S. G. P., *Water Res. Div.*, Bul. No. 212, 1913.

Wells, C. C. *Drainage of Farm Lands*. U. S. D. A., *Reclamation Div.*, Bul. 102, 1910.

Wong, K. *Land Drainage*. New York, 1917.

See also the following list of case-control studies: *Michigan*, pp. 16; *Maryland*, 18; *New York* (Cattaraugus), 24; *Ohio*, 125; *Wisconsin*, 138, 139, 148; *North Carolina*, 174, 175.

soil, and the tendency of the soil to puddle and bake when dry. When the wetness is prolonged, the accumulation of organic matter in the surface soil imparts a dark color. Two drainages causes a mottled color in the soil, and in extreme cases a pale gray color resulting from excessive leaching. When the land is in crop, the wet places are recognized by their watery condition in early spring and after rains, and by the slow starting of the crop. To undo the damage does waste considerable, leaving only those seeds that can withstand the conditions. Harvesting of soil is another indication of wetness. In other cases the wet spots are often marked by the small growth of the plants and by curled, wilted leaves in dry periods. In certain wetlands and mining areas, it is easy to see an indication of defective drainage, especially in the season when the roots of other trees seek to develop. Simply sloping hill land may need drainage quite as much as flat land if it has a compact subsoil overlaid by a peaty topsoil. Water is then trapped in the soil, and is removed very slowly by percolation on top of the hard subsoil and by evaporation. It is wet land in need of drainage.

60. *Drainage needed in humid regions.*—

The amount of land in need of some drainage is very large. Besides the land commonly designated as swampy and marsh, there are very large areas of land devoted to crop production, the fields from which are reduced by the excess of water that they contain at certain seasons of the year. The extent of swampy land varies in different countries, but is likely to aggregate about five per cent of the total area. The cropped land in need of some drainage is very much larger, and roughly aggregates three-fourths of the whole improved land surface. The temporary water

that much land expenditure is often more injurious than the prolonged wetness of swamp land. On the latter there is no loss except on the investment value of the land, which is likely to be low. On the tilted land, however, a considerable sum of money is expended for labor, seed, and perhaps fertilizers and manures, without corresponding return. The loss under these conditions may be heavy, for the ordinary lawn and garden crops, the fluctuation of the soil moisture from a condition of saturated prolonged saturation to the dry and often hard condition that usually results is exceedingly difficult to withstand. Drainage is not desired not only with the surface and the ground water, but also with the subsoil water to the depth to which the roots of crops normally penetrate.

612. *History of drainage.*—The word *land drainage* is the production of the ordinary lawn and garden crops on meadow lands has been recognized from the beginning of historic times. The old Roman landowners (Cato)¹ and his successors of the next ten centuries, in their writings on agriculture pointed out the importance of draining wet soil, and Cato explains how Irrigation of fields should be used in the land. In western Europe² artificial drainage has been practiced for some thousands of years. In England within the last two hundred years drainage by means of pipes has become a general practice.

The practice of artificial drainage by means of ditches was begun in America in the early part of the nineteenth

¹Cato, M. V. *Roman Farm Management* by a Virginia Gentleman. New York: 1913.

²Gillett, C. G. *Engineering for Land Drainage*. New York: 1912.

³Wells, M. *Land Drainage*, Chapter VI. New York: 1922.

⁴French, H. P. *Farm Drainage*, Chapter II. New York: 1921.

century. John Johnston,¹ a Scotchman living near Geneva, New York, carried out the most extensive of these pioneer enterprises, beginning about 1825. A very thorough system of tile drains, aggregating about sixty miles in length, was installed on his farm of three hundred acres, and these drains are still in operation and are producing excellent results.

133. *Effects of land drainage on the soil.*—The cost and value of thorough drainage of the soil can often be better appreciated when a careful survey of its effects on the properties that determine crop growth. From a study of these it may be seen that for the production of the ordinary upland crops a reasonable amount of soil drainage is the first requisite. It may well be termed the foundation of good soil management. The more noticeable effects are as follows:—

1. Drainage permits the development of the granular structure in soils, especially in those containing much clay, and thereby permits the creation of a much better tilth. This is brought about by the frequent changes in moisture content of the soil made possible by drainage, coupled with other natural and artificial agencies, as has already been explained. As a result the soil maintains the open and friable condition favorable for the absorption of rain water, and the circulation of the water in the spaces in the soil without interference with the crop roots. The tendency of the soil to puddle and form lumps, hard lumps is reduced.

2. The withdrawal of the excess water from the lower spaces in the soil permits the admission of air into those

¹ Muller, C. E. *History and Principles of Drainage on the John Johnston Farm*. From *New York State Drainage Assoc.*, pp. 25-32. 1912-1913.

space. This results in better ventilation. The free movement downward through the soil of the masses of water under the pressure of the water in the soil is ventilation by living the water in the soil. The water in the soil is not through the water in the soil but is driven in behind the mass of soil water.

3. The removal of the excess water by drainage provides the soil to maintain a higher average temperature. The high specific heat of water as compared with the soil causes the presence of water to be the chief determining factor in soil temperature. Further, the process of evaporation of the excess water from the soil requires a tremendous amount of heat. The use of water level to remove water and to remove it by evaporation is avoided by draining away this excess. Drained soil not only maintains a higher average temperature in summer, but warms up earlier in spring to a temperature for planting seeds. This gives a longer growing season.

4. The improved ventilation resulting from drainage permits the roots of plants to penetrate deeper into the soil, where they come in contact with a larger supply of moisture and food. One of the indications of the need of drainage is the shallow root development of crops. Stagnant water in a saturated soil is so resistant to the penetration of plant roots as to be almost insurmountable (see Fig. 83).

5. The improved physical condition of the soil that results from drainage permits the retention of a larger amount of the water, and this, in turn, is due to the fact that in a much larger available supply of moisture to the crops.

6. The improved physical condition of the soil permits better internal circulation of water, by which the time and

assured that the excess water is permitted to pass away quickly in the drainage channels.



FIG. 10.—Area of level sandy land, but having numerous wheel tracks containing subsoilers, thereby causing soil particles that flow slowly to form hard crusts. Plants are stunted in such areas. Drainage removes the water and permits slower penetration of the plant roots, thus enlarging their feeding area.

7. The improved ventilation and higher temperatures due to drainage promote the activity of decay organisms, by which dead organic matter is changed into forms that may be well utilized by crops. This aids in the formation of humus, with its beneficial physical effects on the soil.

8. The higher temperatures, better ventilation, better distribution of moisture and of decomposed organic matter, together with the deeper penetration of roots, make available a larger amount of mineral elements from the soil particles.

9. It may now be recognized that there is a distinct *sanitary aspect to soil management*. The accumulation of materials of a toxic nature is prevented by poor drainage, and their destruction is hastened, and perhaps in part their formation is prevented, by the conditions that accompany good soil drainage.

10. Drainage reduces leaching. *Heaving*, or the lifting of crops by frost action in the soil, indicates the presence

of too much moisture in the soil is provided in the pore space. When water forces its equal volume out of its volume. If the soil is too nearly saturated, the expansion is expressed at the surface of the soil by a rising, or heaving, which is exceedingly injurious to most crops that pass the winter in the soil. It breaks their roots and gradually kills the smaller plants out of the ground if the process is many times repeated. When the soil is drained so that free air spaces are distributed through the mass, the expansion of the water as it freezes is taken up in these spaces without heaving at the surface.

11. Drainage reduces erosion of soil by retarding the water through the soil and instead of permitting it to accumulate in the pond, where it must cover over the surface, often with serious results. In order that the drains may be efficient, the soil above the drains must be sufficiently porous to permit the passage of the water as fast as it accumulates.

12. Thorough soil drainage greatly increases the efficiency of all equipment and practice used in crop production on the farm. There is a longer time in which to do the work, a longer season in which the crop may grow, and usually less labor is required in order to fit the land and keep it properly tilled. Further, the crop matures more evenly and is likely to be of better quality. The need for a commercial fertilizer is reduced because of the higher efficiency of the soil.

13. Prompt and thorough drainage of a wet soil results in a large increase in yield and quality of crops. All the common farm, garden, and orchard crops are injured by a saturated condition of the soil, and the drainage that thoroughly corrects that condition permits a large growth of the plants. The fundamental nature of

these changes, and therefore the basic importance of good drainage of the soil, is indicated by the summary of effects. Even where ordinary yields of crops can be grown, improved drainage will usually increase the yield 10 per cent or more; and increases of several hundred per cent are in many cases realized where the conditions before drainage were particularly bad. Land in need of drainage is in many cases fertile in all other respects, and when the soil moisture is properly adjusted, it responds with large yields. Proper drainage should be the starting point in any program of improvement of the soil.

834. Methods of drainage.—Two general methods of drainage are employed: (1) open ditches, and (2) closed drains, or *trench drains*.

Open ditches are most satisfactory where the volume of water to be removed is very large. The general drainage of a region is usually carried in open ditches. They are used where the land is remarkably flat, and especially if the land level is very near the level of the water in the outlet channel so that only a small head can be developed. They are used also where a temporary result is desired.

There are many objections to open ditches, either large or small, especially as applied to tilted land. They make a considerable area of land in the channel and on the banks and they interfere with free tillage operations. In the case of small field ditches this interference is serious. The direct bank prevents the growth of weeds. The shallow surface trenches occasionally used to remove standing water from the land are of very low efficiency, since they do not remove the water from the subsoil and often on so shallow that the surface soil remains almost saturated. Water flows slowly in such rough, irregular channels.

The cost of maintenance of a system of open ditches is heavy, because of weeding, the accumulation of silt, and the growth of weeds, all of which make frequent repairs necessary.

Underdrains when properly constructed are more permanent than open ditches and cost less for maintenance. They do not interfere with surface operations. The latter grade gives them a relatively larger carrying capacity than open ditches have, and their greater depth below the surface permits much higher efficiency in the removal of excess moisture from the root zone.

84. Construction of small open ditches.—Shall fall ditches may be used in the field to remove small accumulations of surface water. They usually consist of a furrow run in the lowest parts and made with a large single-shovel plow, with a turning plow, or with a two-way plow having subharrows to turn the soil on either side. Another modification in the construction of open ditches, which is frequently combined with the turning, is the use of "dead furrows." The land is plowed in narrow beds two or three rods in width, with a deep "dead" furrow between each which drains off some of the surplus water from the higher parts of the intervening rows. A further modification is sometimes used in planting cultivated spring crops on wet land. Ridges are thrown up along each row and the seed is planted on these ridges. The intervening trench (dead) rows drainage.

85. Construction of large open ditches.—When larger volumes of water must be removed, a larger channel is necessary, its size being determined by the area to be drained, the grade of the ditch, its length, its straightness, and the permeability of the soil and bottom. The ideal shape for the ditch for the largest carrying capacity is a

semicircle. In this form the ditch is shallow as deep as it is wide at the surface. This brings the minimum surface in contact with the moving water. The tendency of the banks to cover over the top, as well as the difficulty of constructing such a form, has led to the modification of the walls to an inclined slope that is normally one to one, at an angle of forty-five degrees. This angle is further modified by the nature of the soil through which the ditch passes, and is steeper in clay soil and less steep in loose sandy soil. Where the land is very flat and near the level of the water in the outlet channel it may be desirable to deepen the ditch considerably below the minimum level of water in order to increase the flow during freshets.

The shape may be further modified where the volume of water to be carried varies extensively. A wide channel may be provided to accommodate the flood water, and in the bottom of this channel a smaller channel may be provided for the normal flow, of such a size that it is more likely to be kept clear and free than would a ditch of larger cross section in which the water would be shallower.

An open ditch should be kept as straight as possible to avoid erosion of the bank where the corner. Change of direction should begin gradually and should have the maximum curvature at the middle of the turn. It should then pass gradually on into the straight line of the next division.

The grade will naturally conform in a large measure to the surface of the ground, but it may need to be modified from the natural grade where the slope is so steep as to cause serious erosion. This difficulty requires special attention in constructing roads to carry irrigation water. Sandy soils having low cohesion are most subject to

grains on high grades. Translocated clays are best plotted by means. The grades and rates of flow that are permissible depend largely on the size of the ditch. A velocity of three feet a second is usually the maximum that is permissible. It may be a little higher in clay, but should be a third lower in silt and fine sandy loam. This rate of flow may be attained in ditches when the water is several feet deep by a fall of only six inches in a foot a mile. In small ditches when the water is a foot or less in depth the grade may be from fifty to sixty feet a mile, and in heavy clay, especially if it is compact and sticky, a still higher grade will not cause serious trouble.

These limits depend to a large extent on the character of material that the water carries. Material in suspension greatly increases resistance on the ditch walls.

In constructing open ditches care should be taken to deposit the earth several feet back from the side of the channel. This is desirable for two reasons: First, it removes the weight from the unsupported bank, thereby giving it very little to rest when the soil is saturated; second, it provides a larger channel for the stream should it be inclined to overflow.

Another method of constructing an open ditch, especially in wet ground, is to form a broad, shallow channel by the use of a road machine. The earth is gradually worked back a foot or more, and the walls are so flat, even with a ditch three feet deep, that excess ground may be collected in the bottom of the ditch. This system reduces the loss of land and the interference with farm operations.

681. Construction of early types of canals.—Very material or confidence that affords an underground passage for the flow of water necessarily fills the face

tion of an underdrain. Many methods and materials have been employed. One used in England in clay soil is termed *trink drainages*. A plate having a long, thin drain, with a smaller or *dependent* joint at its bottom, is closely driven through the soil by beam or a rammer. The sponge formed permits for several years in the floor and more coherent slumps of soil, and may do good service. Soil free from stones and having a considerable degree of plasticity is necessary for this method to have much value.

In ancient times, and in pioneer days in America, borders of haggles, limbs, poles, rails, staves, and wooden boxes of triangular or square shape, have been extensively employed for underdrainage and have been very useful. They may still have some use, but they have generally been superseded by more permanent, if not more efficient, materials.

228 Stone drains.—Whenever stones are abundant they have been placed in trenches in some manner and often have served for many years to facilitate the removal of excess water from the soil. When there are flat stones they may be arranged to form a continuous drain. Several systems of arrangement have been used. All drained drains are more likely to be closed by sediment than a drain with no single, direct, flow. Perhaps the safest arrangement is to place flat stones so close to the trench, with their faces parallel to one another and to the walls of the ditch, depending on the irregularities between their faces for the flow of the water. Flat stones are placed over the top of the vertical stones. Where round stones are available the safest method is to place them in the trench without any arrangement except to put the round stones on the surface. The water will find

in way through the openings. All these drains are fairly to be of short duration because of deterioration that takes in the channel by the accumulation of refuse, also promoted by the lowering of ground. The choice of a ditch, to receive above or below, should be relatively large (see Fig. 64).



FIG. 64.—The small variety types of drains, the one and other suitable used for lawn drainage: (1), subdrain with smaller piece of stone in top; (2), subdrain placed two to three feet below surface of lawn; (3) and (4), channel drain, composed of the stone set in different ways; (5), subdrain; (6), channel drain; (7), stone laid flat; (8), stone laid flat; (9), stone laid flat; (10), stone laid flat; (11), stone laid flat; (12), stone laid flat; (13), stone laid flat.

52. The drains. Modern waterlogging is usually accomplished by means of short sections of pipe of baked clay or concrete, placed in the ground sufficiently close to lower the water table in the ground to the desired depth within two or three days. They are given to concrete pipe, and this, coupled with the smooth, hard channel which is not subject to erosion, makes them a very eff-

chert as well as a very prominent source of ball bearings as relatively small cost. If they are well handled and of good material, they should continue to operate for centuries with very little attention. In most cases, the drives have been in continuous operation in America for twenty-five years and are still firm and efficient.

500. Quality of tile. There may be a considerable range in the quality of the made of either clay or concrete. Clay tile consists of several grades of clay and must either end burned at a high temperature. Material that is fired slightly is thereby vitrified, and forms a tile having a very dense, impervious wall. This is vitrified tile, burned at a lower temperature the walls are more porous and less resistant. Some material does not lose of any expansion to which it may be raised, and produces a tile having soft, porous walls. This makes soft, or brick, tile. Still another grade of tile is made of clay - hardy fire clay - slipped into a sub solution before firing. This gives a porous glass, commonly used to cover tile. This is glazed tile.

Of the three grades mentioned, the vitrified tile is usually the best because of its strength and resistance to the destructive agencies in the soil. The most valuable of these agencies is frost. When burned clay cannot resist the destructive action of freezing water. Any tile that has walls porous enough to absorb an appreciable amount of water - and the larger the amount, the greater is the danger - will, if frozen and thawed a few times, be shattered into flakes. The walls of soft tile will absorb explosively from 8 to 20 per cent of moisture, and much the action of frost will go to pieces rapidly. Glazed tile is less injured, especially when the glass is intact; but once a crack has formed the tile is rapidly destroyed.

The vitrified tiles have walls so dense that they absorb less than 3 or 4 per cent of moisture, and about two times 1 per cent, so that they are much less vulnerable to frost action. Good tile should be well flanged and should give a clear ring when struck with a hammer.

Concrete tile of good quality may be made, but the quality is normally inferior to that of the best vitrified tile. The porosity is likely to be 5 to 10 per cent. To make good concrete requires a high proportion of cement, good sand, and as yet a mudding and finishing as is practicable. Several machines of both form and factory size are on the market for molding concrete tile.

Water enters tile through the joints, not through the walls. Even the most porous tile having a high absorption does not permit an appreciable amount of water to pass through the walls. Therefore, soft tile have an higher efficiency than vitrified tile, and, owing to the risk of freezing, the effectiveness of a line of porous tile is much jeopardized. Since water enters at the joints of the tile, short lengths are more efficient than long lengths. The usual length of sections of tile under 12 inches in diameter is 12 to 13 inches. In larger sizes, where the carrying function predominates over the collecting function, lengths of 3 feet are employed.

84. Shapes of tile. — Tile should have a round opening and a round or a hexagonal exterior. A flat-bottomed opening is objectionable because it reduces the flow and promotes the accumulation of sediment. Triangular tile with flat sides are called herringbone, or diamond tile. This shape is unsatisfactory. Tiles are often warped in the process of drying and burning, and the flat-bottomed shape does not allow a close joint to be formed by turning the tile. Round and hexagonal shapes permit inter-

ing until a good joint is formed. An earlier type was the U-shaped tile laid on a board. These tiles are easily broken by the pressure of the mud. They are no more efficient than the ordinary round tile.

141. *Protection of joints.*—Hot water should enter the tile at the lower side of the joint. Any unusual opening in the joint should be on the lower side. If the soil has low cohesion, such as may be the case with fine sand and silt, the upper half of the joint should be protected against the entrance of seepage. A cap of paper or of burlap cloth, two or three inches wide and long enough to cover the upper half of the joint, may be used.

Other methods of protecting joints are to cover them with clay, thick cement mortar, or the soil and gravel soil from the surface. The last named is most commonly employed. Piers may be constructed by placing around the tile a layer of coarse sand or gravel, cinders, straw, or loam. When the soil is of a porous granular nature (fine sand, fine sand or silt filled with water), it may be desirable to place a bed of gravel or cinders under the tiles as well as around them. The entrance of water from the lower side of the joint in small cracks will generally proceed very difficultly from without. Water should flow from a drain approximately close, and any other condition usually indicates a too great entrance of water. When the soil is a fine clay with high cohesion, the ends of tiles should not be so close together as in loose soil. The tops may sometimes be separated an eighth of an inch with cotton string. In such cases it is especially important to return the soil to the trench in a dry condition and to place the topsoil next to the tile.

142. *Entrance of roots into tile.*—The entrance of roots into the joints of the drain sometimes causes a

absorption by breaking up into such a mass of fine particles that the *tile* is finally closed. Any kind of hole or joint may cause this difficulty if permitted to develop under certain conditions. Trouble from continuous wetness where the tile carries water from a spring or some other continuous source, so that in dry periods the water may leak out at the joints into the adjacent dry soil. This leaks the water in the direction of the *tile*. In the absence of such a spring, joint leaks do not appear to interfere with drains. Where a drain carrying water continuously crosses over a line, especially if the adjacent soil is likely to become dry, the joints of the *tile* should be closed by cement.

64. *Protection of joints on curves.* Special care may be needed in order to protect the joints on turns where the water side may be too open. The larger the size of the *tile*, the larger will be the opening on a given curve. Short turns should not be made. Slopes are usually made material to place around the joints of a *tile* under such conditions, especially in soil that is likely to erode easily. If so used, special care should be employed to protect the joints with caps.

65. *Protection for tile.*—The *tile* should have a firm foundation, and if the bottom of the ditch is soft it may be advisable to bed these in gravel or cinders or lay them on a board. Soft muck and quicksand make the most recovery. Ordinarily the bottom of the trench is firmer on the undisturbed earth, which affords a firm setting.

66. *Arrangement of drainage systems.*—The arrangement of a system of underdrains should be determined by the slope of the land and the direction of the soil. No fixed rule can be laid down. The aim must be to place the drains in the line of movement of water in

the soil, and thereby intercept its flow. The need of drainage may arise from several conditions. It is always indicated by the occurrence of a stratum of rubber-sap-pine soil which intercepts the natural flow of water and brings it within the root zone. Sometimes this stratum is near the surface, sometimes it is several feet below the surface. The water may be brought to the surface in a single spring or in a series of springs, in the latter case forming a seepage line. The remaining layer may have an uneven surface and form basins and hollows depicted by a covering of poorer soil. For all these reasons, the drainage condition of the soil and the lines of movement of water through it should be studied as fully as possible before the drainage system is planned. The main lines should first be located. Where the land is in need of drainage in parts, a few lines of tile will accomplish this. Springs holes should generally be tapped by the most direct route. Often, short wing drains may be necessary at the upper end, to collect the underground flow. (See Fig. 45.)

Where there is a line of seepage at nearly a uniform level, a drain placed across the slope at the upper edge of the wet area, and if possible cutting to the underlying hard stratum, will intercept the flow and meet the needs of the lower land. This is an intercepting system of drains.

Where the land is more nearly uniform in its need of drainage, a regular system is required and will usually result in a saving of tile. This arrangement should approximate a rectangular system, in order to avoid double drainage values lateral tile join the main line. This may of course be modified according to conditions. The line of tile should be as long as is practicable for convenience in construction. To this end, if the field

is table in proportion to the length of the main drain, the subdrains may branch out laterally at a right angle or less. If the lands on either side of the main drain join at the same acute angle, the "butterfly-bone" system



FIG. 15.—The final stage of subdrain location, showing the subdrains connected to the main drain and the position of the main drain. In addition to the main drain, the soil is kept wet by the presence of water in the top of the subdrains. This figure also shows the reason for having a main drain above the spring point in order to effect drainage. The subdrains collect the water from the

is formed. If the main drain is situated in the wettest part of the field, this system has some advantage. If the field is long and very narrow, the main drain may be along the short side of the field, with long laterals branching up the slope. If the land is of about equal width on a slope, the drains should ascend up and down rather than across the slope.

Settling of the drain. When the land is relatively flat or convex, a survey should be made in order to determine the distribution and extent of the drains. This is necessary in arranging the system. When the drains are simple, the arrangement may be determined by the eye, if the soil is change in composition.

The drain operates best as a grade of one or two feet in a hundred. Lesser grades are permissible, but in such cases the earth should be carefully packed around the tile in filling. The tile will operate even on the very slight grade of one or two inches in a hundred. In this case the minimum size of tile should be larger than on high grades, and the distribution of the fall should be very uniform. Every part of the operation of planning and construction should be guided by readings of an accurate level.

543. *Depth of drains.*—The depth of tile drains should ordinarily be from two feet to three and one-half feet. The former depth should be the one for clay loam or other moderately impervious soil, and is adequate for most crops having a shallow root penetration. The greater depth should be used on sandy and gravelly soil and where deep-rooted perennials are to be grown. Under special conditions the drains may be laid deeper or less deep than these figures. On very dense clay or where a very impervious hardpan exists, the drain may be placed a little nearer the surface since their function is primarily to remove the water trapped near the surface. To interrupt deep underground flow or to secure an outlet for it, or where especially deep rooting of crops is desired, drains may be laid deeper than the usual.

Where the soil is sufficiently porous to permit reasonable free percolation of water, as in generally well sandy soils, the deeper drains operate earlier after a rain and are the more efficient. The matter of drain necessary is also reduced by laying them deeper. Where the subsoil is relatively impervious, shallow drains should be installed and placed as near the top of the impervious layer as is practicable. A shallow trench should be formed in

the correct layer to receive the tile, and if its depth exceeds half the diameter of the tile special care should be taken to place the tile so as to leave some material on the tile and around the joints in order to insure the extension of water.

(6) *Distance between drains.*—The interval between drains must be determined by the nature and the extent of the soil and the value of the crops produced. In soil where drains must be installed at a depth of two and a half feet or less, for general farming the interval between drains must not be less than 100 feet. Where they may be placed deeper, the interval may be correspondingly greater.

The number of feet and inch of tile required when the lines are laid regularly at a specified distance apart is given in the following table:

| Distance Between Drains | That is, feet line | |
|-------------------------|--------------------|--------|
| | Feet | Inch |
| 20 | 2,176 | 131.00 |
| 25 | 1,740 | 105.00 |
| 30 | 1,424 | 84.00 |
| 40 | 1,068 | 63.00 |
| 50 | 856 | 50.71 |
| 60 | 714 | 42.86 |
| 80 | 536 | 32.00 |
| 100 | 424 | 25.45 |
| 150 | 280 | 17.57 |
| 200 | 216 | 14.18 |

Under the influence of the drain the physical nature of the surface soil and all the natural probability changes and undergoes improvement. Lines of seepage develop,

and the drain gradually increases in efficiency. In heavy soil and in soils having hardpan properties, several seasons may be required for this change in the soil to spread down or flow out from the drains. The problem is to remove the excess water from the soil at the maximum distance from the drains in time to avoid serious injury to the crop.

60. *Construction of drainage trenches for tile.*—Trenches should be as small as possible and yet permit the ready introduction of the tile. Unless the tiles to be used are of the finger size, the ditch should be made from twelve to fourteen inches wide, with vertical sides. Where leveling instruments are employed, the center of the ditch is staked out and the grade level is stretched a definite distance above the proposed grade line of the ditch to guide the machine. In hand digging, the earth is thrown out with a narrow-pointed grade, the loose earth



FIG. 60.—Tools for drainage. (1) and (2), ditching spades for moving the surface of the earth from the ditch; (3), grading wheel used to level the bottom of the ditch and the surface; (4), ditching spade used for moving the earth; (5), shovel for moving the earth; (6), fork used to place tile in ditch, a narrow trench; (7), trowel for leveling ditch and level earth.

is cleaned out with a round-pointed shovel, and the bottom is finished to a smooth, perfect grade by means of the grading barrow, which also smooths the bottom of the trench into shape to receive the tile. (See Fig. 46.) One should be taken care to excavate the trench below the grade line, so that the drainage have a firm bed.

Here and there power are now very generally applied to trench digging. Several types of plow driven by horses are available to loose the soil, and some types are arranged to follow the grade and to elevate the loose earth out of the trench. Several types of engine-driven machines are in use where the hand is not exclusively strong. They cut the trench to the full depth at one operation, and are constructed so as to follow a perfect grade, so that the way is laid as fast as the machine progresses.

62. *Laying tile.*—Where two lines of the pipe they should come together at an acute angle, forming a Y so that the two streams of water will have the maximum thickness and the collection of sediments will be prevented. If the lines are arranged at right angles, one of the straps must be turned down grade in the form of a curve to the last end of its course, to make the proper union. Junction pieces or Y's may be bought in the smaller size of tile. They are rated by the diameter of the lateral and main boundaries; for example, a 3 X 6 junction indicates a three-foot lateral and a six-foot main. A lateral tile should enter the main drain with a slight slope. A small tile should enter a larger main drain at the horizontal center of the latter.

The tiles are placed in the trench by hand, or, if the trench is deep or the tiles are very heavy, by means of some mechanical arrangement such as a hoist. Their

ends are put in line and as close together as conditions seem to indicate is necessary. Any covering or filling material is then put in place. The tile should be placed in the trench as soon as the latter is finished, and the trench should then be at least partially filled with rock in order to avoid danger from freezing or from the corrugals of the walls. The first lot of earth—usually from the surface—is carefully placed about the tiles and tamped in so as to hold them in position. This is called the *binding*, or *back-filling*. The later filling may be accomplished in any convenient way.

362. *Size of tile.*—The size of tile must be determined by the amount and rate at which the water must be removed, the grade of the drain, and the nature of the soil. The small lateral drains whose function it is to collect the water from the soil will usually be of three or four inches internal diameter. Others smaller than this should not be used because of their inclination to become clogged. Small tiles are relatively more affected than larger tiles by the inevitable slight imperfections in the grade. The high friction of the walls of small tiles to the moving water reduces the capacity of flow and encourages the accumulation of sediment. In soft consistencies of the nature of gyttia, sand, and where the grade is less than one foot in a hundred, so the smaller tiles four inches in diameter should be used. As the drainage water is collected by the different lines, the size of the tiles must increase correspondingly.

363. *Amount of water to be removed from land.*—Many things affect the amount of water to be removed from a given area of land. The more important of these are the rainfall, the occurrence of springs, surface evaporation, the storage capacity of the soil, and rate of

evaporation. Underdrains are designed with a capacity to remove only part of the normally *impart* rainfall in a period of twenty-four hours. The absorptive power of the soil and its hardness to the flow of water through its pores provide the use of a flood-drain system capable of removing their consequence is equal to that of water over the drainage surface in twenty-four hours. This system is the drainage coefficient of the area. The drainage coefficient of the system, especially if it is a large system, should be determined after careful study of the present and distribution of the rainfall and the extent to which surface and subsurface water is accumulated.

66. Carrying capacity of a flood-drain system. The carrying capacity of a system of tile drains depends on their respective sizes, their grade, or fall, their total length, their depth in the ground, the straightness of their course, and the smoothness of the interior of the tile. Some of these factors affect the flow directly as they increase, others indirectly. The two most important elements in determining the capacity of a drain are the diameter and the grade. The capacity of a drain varies as the square of the diameter. Doubling the grade increases the capacity by approximately one-third. With certain additional corrections and qualifications, all the factors that affect the flow have been put together in a formula to determine the necessary size of the outlet tile for a given area. This formula, known as Powers' formula, as modified by Elliott¹ for large systems, is as follows:—

¹Wink, C. G. *Engineering for Land Drainage*, Chapter IV, VIII, IX. New York, 1912.

66. RULES: PROPORTION AND RATIO

$$(1) A = \frac{B}{C}$$

$$(2) Q = a^2$$

$$(3) T = 24 \sqrt{\frac{4A + D + \frac{1}{2}R}{1 + 34A}}$$

A = area to be drained

C = coefficient of drainage selected for the area in cubic feet per second. It is determined by the depth of water to be removed in twenty-four hours

Q = quantity of water the tile will discharge, in cubic feet per second

a = area of tile in square feet

T = velocity in feet per second

D = diameter of tile in feet

l = length of tile in feet

k = head, or difference in elevation between outlet and upper end, in feet

h = sum of amounts of load in kilowatts, in feet

n = number of intervals

E = depth of the lower soil surface at upper end, in feet

43 and 54 are factors that take account of gravity, the size of the tile, and the roughness of the walk. The former figure is larger for tile more than twelve inches in diameter.

The first formula determines the number of acres that a given size of tile will drain, by dividing the quantity of water to be removed by the coefficient of drainage selected for the region.

The second formula determines the quantity of water possible to remove, by multiplying the area of the cross section of the tile by the velocity of flow.

The third formula is used to determine the velocity of flow of water in the outlet tile.

In a small system, where the laterals are relatively unimportant and where the soil is fairly close, the velocity formula may be much simplified as follows:—

$$V = 48 \sqrt{\frac{dh}{1+34d}}$$

The term $\frac{1}{3}$ is used only where the soil is so very porous that the ready movement of the water through the soil has no influence on the flow in the tile.

Coefficients of drainage and their equivalents in cubic feet per second of drainage are as follows:—

| Coefficients of Drainage in Cubic Feet per Hour | | Coefficients of Drainage in Cubic Feet per Second | |
|--|---------|--|---------|
| Factor | Decimal | Factor | Decimal |
| 1 | 0.00278 | 10 | 0.0278 |
| 2 | 0.00556 | 20 | 0.0556 |
| 3 | 0.00833 | 30 | 0.0833 |
| 4 | 0.0111 | 40 | 0.111 |

From the above formula Kistler has calculated the number of acres of land drained by outlet tiles of different sizes and grades where the coefficient is equivalent of an inch in twenty-four hours and where the main is 1000 feet in length:—

Amount paid under a Meter-Tank Ratio of Drainage Increased
but Adequately Reduced Drainage Water

| Thickness of Tile (inches) | Values for a Drainage Ratio of 1000000 in a Pipe with Equivalent Permeability to Soil | | | | | |
|----------------------------------|--|------------|----------|------------|----------|------------|
| | 1 inch | 1 1/2 inch | 2 inches | 2 1/2 inch | 3 inches | 3 1/2 inch |
| | Acres | Acres | Acres | Acres | Acres | Acres |
| 5 | 67.3 | 193.1 | 263.1 | 353.1 | 373.1 | 377.7 |
| 10 | 27.9 | 202.9 | 242.9 | 312.9 | 342.9 | 354.4 |
| 15 | 19.9 | 144.9 | 181.9 | 240.9 | 274.9 | 281.1 |
| 20 | 16.7 | 124.6 | 171.3 | 219.9 | 246.2 | 252.4 |
| 25 | 14.7 | 112.4 | 155.3 | 203.4 | 226.1 | 232.6 |
| 30 | 13.0 | 100.7 | 139.0 | 185.6 | 207.2 | 213.1 |
| 35 | 11.5 | 90.7 | 124.0 | 168.1 | 187.3 | 193.3 |

814. Cost of drainage. The cost of tile drainage depends on many things, including especially the use of the tile, the frequency of the drains, the depth, the nature of the soil, the method of digging, and the price of labor. The cost of the drains in different regions and increases rapidly with the size.

The following schedule will serve merely as a general guide in the range in price a thousand feet and a rod when purchased in car lots:

| Cost a thousand feet | Size (Diameter or Length) | | | | | |
|-----------------------------------|---------------------------|---------|---------|---------|---------|---------|
| | 3 | 4 | 5 | 6 | 8 | 10 |
| Cost a thousand feet | \$10.00 | \$12.00 | \$14.00 | \$16.00 | \$18.00 | \$20.00 |
| Cost a rod | \$1.00 | \$1.20 | \$1.40 | \$1.60 | \$1.80 | \$2.00 |

The cost for digging the trench of drains varies widely. In medium and fine-textured soils, for a ditch two and one-

half feet deep to receive the up to ten inches in diameter, the cost may be from \$2000 to \$5000 a rod, with an average of about thirty-five rods. The cost can sometimes be reduced by the use of a power machine. In some and perhaps all the soil may be very much lighter than these estimates. The deeper trench is relatively the more expensive to construct.

Using the 10, filling the trench, and other miscellaneous operations for the smaller sizes of tile will cost at least ten cents a rod. This makes a total cost for five-inch tile of about \$10 cents a rod, \$1 a brooded foot, and \$500 a mile.

Heretofore are available all the rest of drainage on an extensive area of cultivated farm land in northern Ohio, where the soil is chiefly a medium clay loam, somewhat stony, and where the depth was two to three and one-half feet. Some of the work was done by hand and some with the aid of a tractor ditching machine. A fairly low price prevailed for tile, the size ranging from those to sixteen inches.

The results are as follows:

| | Cost on Lawrence Farm, Ohio | |
|---|-----------------------------|----------|
| | Estimated | Actual |
| | per rod | per mile |
| Area tile covered, | 40 | 180 |
| Number of rods of tile, | 3,500 | 9,500 |
| Cost of installation per rod, | \$10.00 | \$10.00 |
| Average cost of tile per mile, | \$10.00 | \$10.00 |
| Average number of rods to the acre, | 15 | 48 |
| Average cost to the acre, | \$50.00 | \$100.00 |

* Continued, L. H., and Effery, H. H. "The Cost of Tile Drainage." Ohio Agr. Exp. Sta., Circ. 147, 1914.

355. *Surface channels*.—When large volumes of water must be carried from about drains in addition to the normal flow, a well-defined tile drain may be combined with an open surface channel for carrying away the flood water. The open channel is located a little to one side of the tile drain so that the latter may not be displaced by possible erosion. The open surface channel is made broad and shallow in order to avoid interference with tillage operations, and, if erosion is likely to occur, it may be banked in grass.

356. *Still basins*.—Still basins are wells in the line of the drain, for collecting sediment that might otherwise be deposited in the tile. The course of the drain is interrupted and a small well is sunk two or more feet below the bottom of the drain. The well extends to the surface of the ground and has a cover. The inlet drain comes in at a slightly higher level than the outlet. The heavy sediment drops to the bottom, whence it may be removed from time to time. The end of the outlet tile is finished with an elbow, turned down so as to prevent the entrance of sticks or other floating material. The walls of the well may be made of wood, concrete, or brick.

357. *Surface intakes*.—The admission of surface water into a tile drain should always be managed with great care to remove the heavier sediment or other material that might obstruct the tile. Screen boxes should be used. The screen should incline to the intake at an angle of thirty or sixty degrees so that floating material, instead of obstructing the flow, will be pushed upward out of the screen.

358. *Outlets*.—As few outlets as is practicable should be constructed for the drain, and these should have a

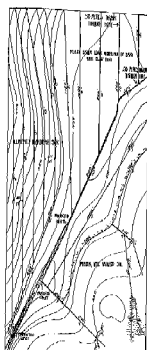


Fig. 57. - A drainage plan of an area of land exhibiting many differences in soil, slope, and degree of wetness. Herein are shown the fields, roads, and arrangements of drain openings to provide efficient drainage under the various conditions.

deep and be well protected by wire mesh. Lines of drains should be connected in systems for this purpose. Unless the drain has a high grade the outlet should not be covered by water. The end of the tile should be protected by a gate or a series of ribs to prevent the entrance of small animals.

606. Muck and peat soil.—Muck and peat soil should usually be drained by open ditches at first. After learning the nature of the material and the structure of the subformation, it may be found permissible to install tile in the smaller ditches. When the organic material is more than five feet deep, so that the soil could not be laid on a hard bottom, much risk is involved in its use due to the excessive shrinkage of such soil when the surplus water is removed and when even moderate drying occurs. If the area is fed by springs so that the water level will be kept permanently at the base of the tile, the shrinkage will be very small and the tile may usually be laid with safety, especially if placed on benches to aid in keeping the alignment. In so-called dry peat, where the material may dry out so severely to prevent the use of tile is undesirable. In muck soil, which has a fine texture resulting from a more advanced stage of decay, the drains may be used with greater safety.

The distance between drains in muck should be from one hundred to five hundred feet, depending much on the nature of the subsoil. Since the surface is likely to be relatively flat, nothing smaller than four- or five-inch tile should be employed and the joints should be carefully protected as described above.

Since the capillary power of muck soil is low, the water table should not be lowered more than two to three feet, depending on the quality of the soil. While the

bottoms of the open ditch may go below this level, it is often advisable to insert check gates to hold the water level when it has been lowered to the desired depth.

961. Drainage of irrigated and alkali lands.—Excessive irrigation and the occurrence of unimpaired seepage has resulted in the waterlogging of extensive lands of arid and semiarid land, and in the serious deterioration of alkali soils in the arid soil. An effective remedy for this condition is the installation of a thorough system of drains¹ preferably underdrains, coupled with heavy irrigation by means of which the excess salt is flushed out in the drainage water. The most serious alkali land is now being effectively reclaimed by drainage, for the production of substantial crops.

For this purpose drains are installed deeper than is the custom in humid regions, in order to remove the capillary rise of moisture to the surface of the soil, where the alkali salts are deposited in injurious amounts. The drains are often placed at depths of from four to 20 feet. Special care is also taken to intercept the underground seepage. Sometimes the seepage water from leaky canals and reservoirs and from over-irrigation may run long distances in porous gravel strata and rise to the surface of the land on encountering some impervious obstruction. In such cases wells may be sunk many feet to the water-bearing stratum, and the water thus conducted away in drains far enough below the surface to avoid injury to the soil.

Many special problems are encountered, such as the occurrence of boriflora—usually a stratum covered by alkaline carbonate—and the development of a serious

¹Wheeler, C. G. Development of Methods of Draining Irrigated Lands. U. S. D. A., Office Rep. No. 226, Rept. 78-656-658. 1910.

gradual condition of soil. The bowden may need to be partially broken up by drainage. The latter condition may require the placing of the tile on bowden or the use of moored bent drains to keep the alignment.

Coupled with deep drainage, sufficient irrigation water is required to produce heavy permeation, by means of which the excess salt is removed. The most alkaline land can usually be reclaimed in two or three years of leaching.

102. *Vertical drainage.*—A gravity outlet for drainage is sometimes difficult to provide. In such a case it may be possible to remove the drainage water through some porous stratum below the surface. There must be such a porous stratum within reach below the surface, in order to render the method of vertical drainage practicable. Basin-shaped areas without an outlet may be wet because of the accumulation of a thin layer of clay or other impervious material in its lowest part, beneath which at a short distance is a porous gravel or sand formation. Anything that perforates this impervious layer and keeps open the passage will affect drainage. With several feet in diameter may be constructed and filled with stones. The drains and open drains have been emptied into such structures. An opening of temporary efficiency may be formed by a charge of dynamite. The tendency of such an opening, however, is to become clogged.

A second condition under which vertical drainage may be advisable exists in a soil that is unrelieved within a few hundred feet by a limestone or other porous rock formation into which the surface water may be supplied. A casing may be installed to protect the walls of the well and to reach from the surface to the porous stratum. In addition a trapped intake, coupled with a silt basin,

may be placed at the top of the well to insure its continuous operation. Extensive surveys of underwater mines reported to have been destroyed by this arrangement, show it might otherwise have been necessary to go a long distance in order to obtain an effect. It should be noted that in many cases a sufficiently porous structure is better in the shape of the surface portion of the mine, so that the mineral could not often be employed.

10. Damage by means of explosives.—The use of explosives in producing damage has been proposed for three conditions:—

1. To break up a hard rock and possibly make a connection with some porous structure below, so that the well could better handle the normal rainfall. This is clearly related to the operations of subsoiling.

2. To break through a thin superincumbent layer in the bottom of a wet low-lying area. This is identified with surface drainage headwaters.

3. To open up channels for drainage purposes. This one is the most extensive. By proper distribution of the charges of explosives, coupled with favorable soil and weather conditions, a very good channel can be opened by this method. It is noted only in the operation of open ditches of various size, three feet or more in width, and it has the greatest advantages where the land is much obstructed by stone or stumps. The form of the explosive largely determines the depth of earth and destruction. No very accurate grading of the bottom of the ditch can be accomplished by this method.

10A. Disposal.—The removal of the excess water from the soil by any means constitutes drainage and is one of the most fundamental operations in soil management. The effects of adequate drainage are numerous

and tree-planting. In its accomplishment the physical properties of the soil and its resistance relations must be taken into account. Whether open ditches or under drains are employed depends on the local conditions, but where practicable underdrains are always to be chosen. While the cost of drainage is a considerable sum, the improvement when well made is of long duration and the cost may therefore be distributed over a long period. The benefits accrue not only to successive crops, which are generally large, but also to the working of expense in operation. Good drainage is the basis of good soil management.

CHAPTER XXIX

TILLAGE

WHILE the farmer depends somewhat largely on the weathering agencies for granulation of his soil, numerous tillers can be obtained only by certain external operations. The advantages to be derived from tillage have been pointed out. The importance of the addition of lime and organic matter as a means of soil improvement has been explained. Yet, after all these have been provided, a further fundamental practice remains to be followed. This practice is tillage, or the manipulation of the soil by means of implements so that its structural relationships may be made better for crop growth.

Tillage is so general in its application, so pronounced in its effects, and so complex in its modes of operation, and has to do with so many machines employing different mechanical principles, that it requires description by itself.

864. *Objects of tillage.*—Tillage aims to accomplish three primary purposes: (1) modification of the structure of the soil; (2) disposal of rubbish or other coarse material on the surface, and the incorporation of manures and fertilizers into the soil; (3) disposition of weeds and plants in due and in position for growth.

The next progression of these purposes is the modification of the soil structure. This affects the retention and movement of moisture, aeration, and the absorption and retention of heat, and other properties or results due

growth of organisms. Through all these factors the composition of the soil solution, and finally the penetration of plant roots, is influenced. The creation of a soil health is merely a change in the structure of the soil at such times and in such a manner as will prevent escape of moisture. For this reason it is essential to understand the relation of soil structure to the movement of moisture in carrying the water. In a frost-affected soil, in which the granular or crumb structure is most desired, tillage may have an important influence on the formation or destruction of granules. As has been pointed out, any treatment that increases the number of lines of weakness in the soil structure facilitates the action of the moisture lines and the external material in solidifying the soil granules. Tillage shatters the soil and breaks it into many small aggregates which may be further drawn together and loosely cemented as a result of the evaporation of moisture. The more numerous the lines of weakness produced, the more pronounced is the granulation; and, conversely, the fewer the lines of weakness produced, the more mass and solidity in the structure.

195. *Impacts of tillage.*—The implements adapted to the manipulation of the soil are very numerous and embrace many types. Many operations are represented by the term tillage, which includes the use of all those implements that are used to move the soil to set way in the practice of crop production. It includes the smallest hand implements as well as the heaviest type farm machinery.

196. *Effects on the soil.*—All these operations may be divided into two groups, according to their effect on the soil,—those that loosen the soil structure, and those that compact the soil structure. In the subsequent

paragraphs of this chapter the effect of the commoner types of tillage implements on the soil are pointed out as a guide to their selection for the accomplishment of a desired modification. Good soil management consists, first, in analyzing the soil condition, in order to determine the change that should be effected, and second, in the selection of the implement or other treatment that will most readily and economically accomplish the object.

60. Classes of tillage implements.—According to their mode of action, tillage implements may be divided into three groups—plows, cultivators, packers and crumbers.

61. Plows. The primary function of a plow is to take up a ribbon of soil, twist it upon itself, and lay it down again behind side by side, or partially so. In the process two things result: (1) if the soil is in proper condition for plowing, it will be shattered and broken up; (2) the soil is partially or wholly inverted, and any rubbish is put beneath the surface.

62. Pulverizing action of the plow.—In twisting, the soil tends to shew into thin layers, as already pointed out (page 149). These layers are moved successively upon each other, so the beams of a book when they are bent. The result should be a very complete breaking-up of the soil. How thorough the breaking up will be will depend on (1) the condition of the soil, and (2) the type of plow. As to the condition of the soil, there is a certain optimum moisture content at which the best results will be obtained. That condition of moisture is the one that is best for plant growth. Any departure from this optimum moisture content will result in less efficient work. It has been said that, in proportion to the energy required, the plow is the most efficient pulverizing implement used by the

harrow. The optimum moisture content for plowing is indicated by that moist state in which a mass of the soil, when pressed in the hand, will adhere without puddling but may be readily broken up without injury to the intrinsic soil structure. This is a much more critical stage for frost-affected soils than for nonfrozen ones. Sandy soils are not greatly altered by plowing when out of optimum moisture condition. On the other hand, if a clay is plowed when it is saturated with water, it will be thoroughly puddled and will dry out into a hard, lumpy condition. Such a structure requires a considerable time to remedy.

601. *Types of plow* (Fig. 60).—There are two general types of turning plows, the common moldboard plow and the disk plow. Their mode of action is quite different, although, so far as the soil is concerned, the result is much the same. The moldboard plow seems to have a wider application than the disk plow, but both have a particular sphere of usefulness.

The disk plow is essentially a large revolving disk set at such an angle that it cuts off and inverts the soil, at the same time pulverizing it fairly effectively also. The manner of the moldboard plow. One advantage claimed for the disk plow is its lighter draft for the same amount of work done, due to its having rolling friction in the soil instead of sliding friction. In practice it appears to be especially effective on very dry, hard soil and in turning and covering subsoils.

For any given texture of soil and any given till condition, there is a type of plow, a shape of moldboard, and a depth of furrow slice, that will give the best results. This fact is to be kept constantly in mind in plowing soil. Soil hard requires a different shape of plow from friable

an overhang, found as what is called the *rod plow*. This usually cuts off the roots at the bottom of the slice, thereby and gradually breaks the soil over without breaking the soil, and lays it smoothly up to the previous furrow slice. (2) The short, steep *subsoiler* with a *subsoil* overhang. This is not adapted to soil hard, because it breaks up the soil and shoots it over in a rough, jagged manner with uneven tilling. But on *loose* soil, in which it is adapted, it very completely breaks up the soil and throws it over in a *very* level, *uniform* manner. The pulverizing effect is obviously much greater than with the *rod plow*. Hence the *steep subsoiler*, or *follow-ground* plow meets the most favor on the soil in a given time at a given speed of movement, it follows that if a particular soil is over-set it should be plowed with the *rod plow*; while, if it must be plowed when too dry, the *follow-ground* plow will be more effective. Consequently the *drill*, which will probably be larger in the latter case.

372. Position of the furrow slice (Fig. 60).—Considerable care should be taken concerning the angle at which the furrow slice is placed. It is seldom desirable to completely invert the soil. If it is too flat, the stable soil which lies trapped at the bottom of the furrow will tend to interfere with capillary movement for a considerable period. This may cause serious difficulty in spring-plowed soil, where the capillary connection does not have time to be renewed before a very serious frost. If, on the other hand, the furrow is too steep, the proper pulverization does not take place and the heavy under of stable and rubbish is not satisfactorily accomplished. The stable and rubbish are likely to interfere with subsequent operations.

The best angle at which to turn the furrow slice is

placed from 20" to 40" with the horizontal. A furrow thus set functions readily entrance for rain water and facilitates the best of aeration for the soil. Such an angle is especially to be recommended for turning under green manures. The capillary excretion with the soil will not be broken and the green material is well distributed from the top to the bottom of the furrow. When a seed is to be placed, a furrow turning of the furrow is substituted in order to prevent the packing and avoid the danger of the soil's reacting with subsequent cultivation.

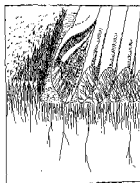


FIG. 10.—Section of plowed field showing the normal composition and position of the furrow and its effect on the soil. The furrow is shown as being turned over the surface soil and on the position of furrow under vegetable treatment.

FIG. 11.—Depth and width of furrow. — There is a general relation between the width of the furrow and its depth. In general, it may be said that the ratio between

two is width to one in depth. The greater the depth, the less in proportion may be the width of the furrow slice.

On clay soil in particular, there is also a relation between depth and condition. A wet soil should be plowed more shallow, other things being equal, than a dry soil, because the puddling arises in less. On a dry soil the depth should be increased, in order to increase the pulverization. Considering these principles, then, it may be said that if a clay soil must be plowed when too wet, it should be plowed with a wet plow and to no shallow a depth as is permissible. But on no sandy soil the opposite conditions should be fulfilled—that is, the use of a steep moldboard and to an increased depth. Likewise, on sandy soil, where the aim is generally to compact the structure, this may be furthered by deep plowing with a steep moldboard when the land is even-set.

III. *Flow rate.*—In connection with this phase of the subject it is important to consider what is often called the "plow side,"—that is, the soil at the bottom of the furrow, which bears the weight of the plow and the dragging of the team, and which under a uniform depth of plowing does not become loosened. In clay soil, especially, it gradually becomes more compact, resulting in fine smothering of a hardpan character, which is detrimental to the circulation of air and moisture and interferes with the penetration of plant roots. Consequently, occasional deep plowing, or even subsoiling, is resorted to break up this unfavorable soil structure. There is less tendency for this disk plow than for the moldboard plow to form the "side."

IV. *Ballistic plow.*—The ballistic plow is a modified form of the moldboard plow. It has a flexible curvature to the moldboard, so that it is essentially two plows in

are. The plow enters on a wheel in such a way that it may be locked on either the right or the left side. It removes the necessity of plowing in beds, and, by permitting all the work to be done from one side, enables the plowman to lay the furrow slices in one direction. On the hillside this direction is down the slope, because of the greater ease in turning the soil in that direction. This plow also removes the difficulty of pulling up and down the hill. There is another type of moldboard plow, designed to eliminate "dead furrows" and "lack furrows." Dead furrows are developed by the left horse slices of two heads being drawn in opposite directions, thereby leaving a gallery between, which is often unproductive in character; the head furrow consists of two furrows drawn together, usually forming a ridge more productive than the average of the head. This plow is of the subsoil type, the plow being carried on wheels and regulated by means of levers and the traction power. Two plows are needed, one having a right-hand turn to the subsoil, and the other a left-hand turn. By using one plow in one direction and the other in the opposite direction, it is possible to begin on one side of the field and throw the furrow slice in one direction until the entire area is covered, thereby leaving the soil in a uniform condition. Such plows, being heavier than the single, walking plow, are not adapted to very uneven ground.

87. *Covering rubbish.*—The secondary function of the plow is to cover weeds, manure, and rubbish that may be on the surface. This also the turning plow does very effectively. The mowing and turning of the soil, rubbish, and weeds is facilitated by several attachments, such as rollers, jumpers, and drag chains. These

are several types of cultivars. Blade cultivars are attached to the beam or to the share in such a manner as to let the furrow slice free from the hard soil. They should be adjusted in such a position as to cut the soil after it has been raised and put in a disturbed condition, at which time the roots are most easily severed. This position is a little back of the point of the share. A knife type attached to the share is commonly called a disc cultivar. A pointer is a miniature rockharrow attached to the beam for cutting and turning under the upper edge of the furrow slice, so that a seed, when later sown, will not be without the exposure of a rugged edge of grass which may retard growth. This is used chiefly on soil land. A drag chain is an ordinary heavy log chain, one end of which is attached to the control part of the beam and the other to the end of the chisel bar on the furrow side, and with enough slack so that it drags down the vegetation on the furrow side just ahead of the turning point. It is used primarily in harrowing under heavy growth of weeds or grass-meat crops.

678. Subsoil plow.—There is a third type of plow, the so-called subsoil plow. The purpose of this implement is to break up soil beneath the wheel without turning the material into the soil. It consists essentially of a small, pointed steel on a long shank. This implement is drawn through the bottom of the furrow, and shatters and loosens the subsoil to a depth of 18 inches or 2 feet. It is often used on soils having a dense, hard subsoil. For one requires the exercise of judgment, as the grooves may prove very injurious if done out of season. As a general rule, it is best to use the subsoil plow in the fall when the subsoil is fairly dry and easy in a measure to be recompactified by the winter rains. Spring subsoiling is

action advisable in humid regions, owing to the danger of pollarding the soil, or to the possibility of its remaining too long for best root development if the work is done when the soil is dry enough not to puddle.

85b. *Collimators* (Fig. 70).—There are many types of collimators than of any other form of soil-working implements. These may be grouped into (1) collimators proper; (2) broader and heavier types of collimators; (3) roller collimators. These implements agree in their mode of action on the soil in that they lift up and move it aside, with a stirring action which loosens the surface and cuts off weeds, and to a slight degree covers with. However, the action is primarily a stirring one, and, in general, it is much shallower than that of the plow. One important fact should be kept in mind in cultural operations, especially those just following the plowing, that is, the work should be done when the soil has the right moisture condition. Particularly is this true in the system now following the plowing. Plowing, if it is properly done, leaves the soil in the best possible condition to be further pulverized. It is properly moistened, and if the clods are not shatterd they are reasonably firm and very be much more readily broken down than when they are permitted to dry out. In drying they are somewhat cemented together and thereby hardened. Not only is it desirable in almost all cases to take advantage of this condition of the soil, but the leveling and pulverizing of the soil reduces drying and improves the character of the soil bed.

86. *Collimators proper*.—There is a great variety in types and patterns of collimators. They may be divided into large shovel form and small shovel form, and the duck-foot form. The first type has a few more

usually large wheels set rather far apart, which rip up and turn up the earth to a considerable depth and leave it in large ridges. There is a lack of uniform action, and the bottom of the cultivated part is left in hard ridges. Such implements are now much less used than they were formerly, and may be considered as replaced in a measure by the use of the plow, where deep working without turning

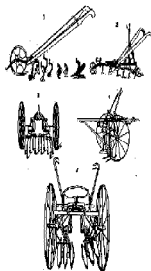


FIG. 11.—Types of cultivators: (1) wheel barrow with hand guide, self-adjustable wheels; (2) portable machine, cast-iron frame, with friction drive shaft; (3) two-wheeled portable machine; (4) two-wheeled machine with hand guide; (5) two-wheeled machine.

is desired. Some of the wheel bars used in orchard tillage belong to this type. The single and double shovel plows are rather typical of the same implement.

The small wheel cultivators have very generally supplanted the large shovel type in most cultural work. The decrease in size of shovels is made up by the great increase in number. Obviously they operate to shallow depths, but very thoroughly and uniformly. They are now much preferred in all orchardage work for eradication of most weeds and the formation of a loose surface mulch.

The disk-hoe cultivator—or creep as it is called in the orchard states, where it is extensively used in the cultivation of cotton—is a broad blade that operates in a nearly horizontal position an inch or two beneath the surface. The surface layer of soil is moved and mixed slightly from the sides out and is somewhat disturbed in the operation. This tool is very efficient in establishing and maintaining a weed and in destroying weeds. It covers every part of the soil. The implement is increasing in popularity in the northern and eastern states. It is well adapted for use in very dry or hard soil.

Another classification, which has been relative to utility than to the maintenance and conduct of the operation, is based on the presence or the absence of wheels. There is a strong movement toward the use of wheel cultivators carrying a seat for the operator. These have a wider range of operation as to depth and facility of movement than have the cultivators without wheels.

Still further, there is the distinction of shovels from disks. Disk are used on the larger cultivators but seldom on the small ones.

Cultivators may be constructed to till one or more rows at a time.

961. *Reeder and harrow types of cultivator* (Fig. 77). — In this group are the spike-tooth harrow, the smoothing harrow, the spring-tooth harrow, the disk harrow, the grading harrow, weeder, and the *hara* and *Kicker* harrows.

The spike-tooth harrow is essentially a leveling implement, adapted to very shallow cultivation of loose soils. It is also something of a weeder, in that it picks up surface rubbish. The spring-tooth harrow works more deeply than does the spike-tooth harrow, and can therefore be used in many soils for which the latter is not adapted. In working down cloddy soil it brings the lumps to the surface, where they may be crushed. The disk harrow depends for its primary advantage on the conversion of cloddy fractions into rolling fractions. Its draft is therefore less for the same amount of work done. It has a vigorous pulverizing action similar to that of the plow, surpassing shod cultivators in this respect. The disk harrow is not adapted to stony soil, but the method forms are as effective on such soil as on soil free from stones, as long as the stones are not large enough to collect in the implement. On the other hand, on hard soil of coarse texture, sand, and the like, the disk harrow is the more efficient. The grading harrow (strawny disk) is very little different from the disk harrow, except that it takes hold of the soil more readily. A great attempt to bring about a high degree of pulverization, and with greater uniformity, is represented by the double-disk implements. In these implements there are two sets of disks, one set in front of and engaged with the other, and the two subjected so as to throw the soil in opposite directions.

Weeders are a modified form of the spring-tooth harrow, adapted to shallow tillage of friable, easily worked

soil, where the aim is to kill weeds and create a fine granular mulch. They are wide and are fitted with blades, and therefore leave an intermediate place between cultivation proper and harrows. They are much used for sowing of young crops.



Fig. 19.—Seven types of harrows: (1), spring tooth; (2), wooden disk; (3), wooden disk with iron teeth; (4), wooden disk with iron teeth and a spring; (5), wooden disk with iron teeth and a spring; (6), wooden disk with iron teeth and a spring; (7), wooden disk with iron teeth and a spring.

The *spring harrow* consists of a series of pointed blades which cut the soil and work it loose. They are most useful in the later stages of preparation of soil relatively free from stones. The *wooden harrow* is a modified form of disk, used primarily for pulverization. It consists of a series of bars of small disks arranged in a straight row, and is especially adapted to breaking up hard, lumpy soil.

In this particular it may be considered as belonging to the third set of implements, the chisel crushers. But as compared with the roller on hard soil it is more efficient.

602. Seeder cultivators.—Many implements used primarily for seeding purposes are also cultivators, and their use is equivalent to cultivation. The grain drill is a good example of this group. It is essentially a cultivator—either shoe or disk—adapted to depositing the grain in the soil at the proper depth. All types of plowages that deposit the grain in the soil have a similar action on the structure of the soil. The ordinary two-row malleable planter, the potato planter, and the like, while of low efficiency as cultivators, will have as effect which is unaccountable. This action is well seen in the later, and for planting series, by which the grain is deposited beneath the furrow, which is filled by cultivation after the grain is set. The later is generally used without previously plowing the ground, and its use is limited to regions of low rainfall where the soil is altered by natural processes. Plowed ground later has lately been introduced, which combines the advantages of deep planting with proper preparation of the soil.

There is also a very considerable change action in many harrowing implements. The potato digger, for example, very thoroughly breaks up and cultivates the soil, and the process is one important reason for the general high yield of crops following the potato crop. Even harrowers and beat-harrows also have a similar action on the soil.

603. Pickers and crushers.—These may be divided into two groups—those implements that aim to compact the soil, and those the primary purpose of which is to pulverize the soil by breaking the lumps. Both kinds

of implements have something of the same action on the soil. That is to say, any implement that crumples the soil does a certain amount of crusting; and, conversely, any implement that crumbles the soil does some compaction.

386. *Rollers* (Fig. 17).—The type of the first group is the solid, or barrel, roller, which by its weight tends to force the particles of soil closer together and to smooth the surface. The smaller the diameter in proportion to its weight, the greater is the effectiveness of the roller. Its *draft* is correspondingly greater. As a crusher, the roller is relatively inefficient on hard, lumpy soil, because of its large bearing surface. Lumps are pushed into the soft earth rather than crushed.

It should be mentioned that there is one condition under which the roller is effective in breaking up the soil structure. This is on fine soil on which a crust has developed as a result of light rainfall. Here the roller may break up the crust and restore a fairly effective soil matrix.

Another form of roller is the subsoiling roller. One type of this implement consists of a series of wheels with narrow, V-shaped rims, which press into the soil and exert, it while passing, the surface loose. The wheels are designed primarily to smooth the land after plowing, and to bring the furrows close together and in good contact with the subsoil, in order to conserve moisture and promote decay of organic material that may be plowed under. This roller has been developed chiefly in semi-arid and arid sections of country where the conservation of moisture is especially important, but it might well have a much larger use for the same purpose in sections of the country that are subject to late summer and fall

draughts. While composing the soil, this implement leaves a mulch.

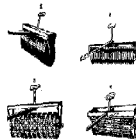


FIG. 75.—Types of garden and subsoil rollers: (1), solid or barrel roller; (2), corrugated roller; (3), roller and subsoil roller; (4), bar roller.

106. Chalk crushers. The aim of these chalk crushers is to break up lumps. As to mode of action, there are several forms. The corrugated and the bar roller and the chalk crusher concentrate their weight at a few points, and are open enough so that the fine earth is forced up between the leading surfaces. They are very effective in reducing lumps and to comparatively fine tilth. They have very little levelling effect further than the breaking down of lumps.

The plough, drag, or flat, uniformly levelled, on into essentially of a broad, heavy weight without teeth which is dragged over the soil. The lumps are rolled under its edge and ground together in a manner which very effectively reduces their size. At the same time the soil is levelled, smoothed, and, to a degree, corrugated. This implement may well be used in the place of the roller.

as a pulverizer, on many occasions. It is constructed in rotary form.

III. Efficient tillage.—Efficient tillage requires an understanding of the properties of the soil, good practical judgment as to its condition, fidelity in the selection of the proper implements for its treatment, and an absolute skill in their operation. The more exact way often he attained in different ways, and the practical accuracy that frequently aims for the farmer to get on with a relatively few tillage implements when a variety of soil conditions must be dealt with *drum* hardly on his responsibilities.

CHAPTER XXX

IRRIGATION AND DRY-FARMING

IRRIGATION¹ is the application of water to the soil for the purpose of growing crops. It is supplementary to the natural precipitation. The quantity of water applied and the time of application must therefore be determined by the character of the soil.

THE selection of irrigation to cultivate.—The limits of rainfall where irrigation becomes necessary is not a fixed

¹ Wilcox, J. A. *Principles of Irrigation Practice*. New York, 1914.

Chas. W. R. *American Irrigation Practice*, Chicago, 1913.

Doorn, A. *Practical Irrigation*. New York, 1905.

King, P. B. *Irrigation and Drainage*. New York, 1898.

Colburn, W., and Whipple, G. R. *Practical Gardening and Irrigation*. New York, 1910.

Wood, F. D. *Irrigation*. New York, 1902.

Mead, R. *Irrigation Institutions*. New York, 1903.

Mead, R. *Proportioning Land for Irrigation and Methods of Applying Water*. U. S. D. A., Office Rep. Sta., Bul. No. 161, 1904.

Wilcox, J. A. *Irrigation among Prairie Growers on the Middle Cross*. U. S. D. A., Office Rep. Sta., Bul. No. 155, 1902.

Wilcox, J. A., and Macmill, L. A. *Methods for Increasing the Crop Producing Power of Irrigation Water*. Utah Agr. Exp. Sta., Bul. No. 191, 1912.

Forbes, E. *The Use of River Water Supplies for Irrigation*. U. S. D. A., Yearbook, p. 601, 1897.

Forbes, E. *Irrigation of Orchards*. U. S. D. A., Farmer's Ed. 494, 1899.

current. Irrigation is practiced in all parts of the world—in those regions where the rainfall is 40 and 60 inches a year, as well as in those regions where it is only 20 inches or less. (See Fig. 72.) The need of irrigation is determined by (1) the time when the rainfall occurs, (2) the way in which it occurs, whether in small or

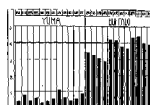


FIG. 72.—Diagram showing the relative need for irrigation of small areas and regions (Young, Adams), and a humid region (Old, Adams).

large quantities, (3) the nature of the soil, (4) the air temperature and wind movement, and (5) the nature and value of the crops grown. Other factors, such as the cost of applying water, methods of tillage, and market facilities, have some influence in determining the practicability of irrigation. Irrigation is usually associated with a low rainfall of 20 or 25 inches a year. Using these figures as a measure of the need of irrigation throughout the world, it appears that about 40 per cent of the earth's surface has so low a rainfall that irrigation is necessary in order to secure payable yields of crops. About 25 per cent of the earth's surface receives 30 inches or less of rainfall annually. About 10 per cent receives between 10 and 20 inches, and about 15 per cent

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receives between 20 and 30 inches. Every continental area has its wet portion where the rainfall drops below 10 inches. (See Fig. 76.) These sections are usually in the interior, but their position depends on the topography of the land and the direction of the moisture-laden winds. Sometimes, as in the western United States, the coastal mountain ranges do not extend to the adjacent interior valleys, some of which extend quite far into the areas as in southern California.

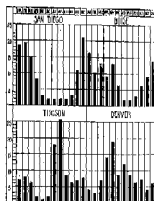


FIG. 74.—Four types of rainfall. The diagrams show the distribution by month.

It has been estimated that the total available water supply is sufficient to irrigate only one-tenth to one-fifth of the proportion of the earth's surface in need of such treatment.

68. **Extent of irrigated land.**—In 1905, Wood¹ estimated the total area of land irrigated at 100,000,000 acres. Since that date the practice of irrigation has been extended rapidly in all parts of the world, and it is probable that at the present time the total area of land irrigated is at least 200,000,000 acres. In Egypt, in Australia, and in India, as well as in the United States, large projects for irrigation developments have recently been undertaken. In the United States, according to the Thirteenth Census, the area of land irrigated increased 750,000 acres between 1880 and 1900. At the latter date extensions for the period of water were under way to cover a total of 31,000,000 acres.

69. **History of irrigation.**—The practice of irrigation is very ancient. The very earliest records of the peoples in the valleys of the Nile and Euphrates rivers, in Africa and Asia, mention large irrigation works. In China and India also the practice is very old. The remains of ancient works for irrigation often cause the modern engineers by their size and complexity of construction, considering the facilities that were available. As early as 2800 B. C. so artificial are the canals in the civilization now commemorated in Egypt, communicating with the Nile through a canal. The Great Canal in China, connecting the Hoangho River with the Yangtze, was 450 miles long and had several lakes in its course. In Persia, Mesopotamia and the entire eastern United States, there exist remains of very extensive irrigation works of great antiquity. In Argentina large irrigation canals may still be traced for some days to have been

¹ Wood, E. *Irrigation Engineering and Practice*. American College of Agriculture, p. 604. New York, 1905.

valley. In the Yucle River valley in Arizona, remains of the cliff dwellings, which were civilized long before the advent of the Spanish explorers, are associated with extensive irrigation canals showing much skill. The ditches and the reservoirs were finished with hard boulders tamped or burned clay, and in one instance a main canal was cut for a considerable distance in solid rock. Sometimes a smaller ditch was sunk in the bottom of a large canal, to facilitate the movement of small runs of water. The ancient canals in the Salt River valley¹ had a length of at least 150 miles and were sufficient to irrigate 250,000 acres of land.

In modern times the great American dam has been built on the Nile River, and with the associated reservoirs it is designed to control the flow of the river and provide water for irrigating. It stands as an example of present-day irrigation development and control.

890. Development of irrigation practices in the United States.—In the United States the earliest modern people to practice irrigation were the Catholic missionaries in southern California. The irrigation predecessors of the present irrigation systems in the United States were built by a colony of San Francisco and forty-seven Mexicans who went into the Salt Lake valley in Utah in July, 1847. The crops of these people were grown with water diverted from City Creek, and their community 185, together with their peculiar situation, led them to work out in the succeeding decades the fundamental principles of economic and social life as adapted to irrigative farming. In the last thirty years the practice of irrigation has

¹Perkins, J. H. *Irrigation in Arizona*. U. S. D. A., Office Rep. Ser., Bul. No. 323, p. 9, 1911.



extended rapidly in the western United States. It has approximately doubled each ten years since 1870.

Irrigation is employed somewhat generally throughout the region west of the 100th meridian, which runs through central Nebraska. With few exceptions of limited areas, the annual rainfall is less than 25 inches, and over large areas it is less than 15 inches.

The methods of securing water and applying it to the land have grown up gradually out of the experience of the people in many communities and under many conditions. Coöperative effort of some sort is essential to provide water for irrigation, and this has led to the use of several types of organizations for the purpose. Naturally, the states concerned have taken a part in the matter by passing laws and providing funds to promote irrigation practices. Finally, the aid of the Federal Government was enlisted. The enterprises for the provision of water for irrigation may be divided into seven groups, chiefly according to their legal status: (1) commercial enterprises selling water for profit; (2) partnerships among individual farmers without formal organization; (3) coöperative enterprises, made up of water users; (4) irrigation districts which are public corporations; (5) Carey Act¹ enterprises, by Federal enactment authorized August 19, 1894, and made up of groups in the arid and semi-arid states, these states being held responsible for the irrigation of these grants; (6) United States Indian Service enterprises, to provide for the construction of irrigation works in Indian reservations; and (7) the United States Reclamation Ser-

¹ *Thomson's U. S. Census*, Chapter 14, p. 421. 1910.

² *McNee, A. P.* Irrigation under the Carey Act. U. S. D. A. Office Rep. 506, Ann. Rept. pp. 267-268. 1905.

ing, published by *Ecology* for June 17, 1904, pointing for the maintenance of irrigation works with the proceeds from the sale of public lands in the arid and semi-arid states.

These several provisions and their successive growth in time suggest the necessity of large enterprises and careful coordination in providing water for irrigation. The many attractive features of farming in arid regions make irrigation, together with the publicity that the enterprises have had, have hastened the growth of irrigation farming so that it now plays a very important part in the agricultural business of the country.

III. Irrigation in desert regions.—In the humid states that is, those in which there is a large normal rainfall and in which crops can usually be produced without artificial addition of water—irrigation has been practiced to some extent. Irrigation is used (1) where the crop has a high value, as for vegetables and small fruits near large cities; (2) where the quality of the crop is much affected by unfavorable conditions, as the production of orange groves in southern Florida and of rice in Louisiana; (3) where the soil is especially sandy; and (4) where the supply of water may be very cheaply applied to the land, as in the diversion of streams to wheat fields, usually meadows. In Great Britain and in central and southern Europe, the difficulties of stream to ranchy grass meadows is relatively serious. Under all these conditions, small irrigation enterprises have been developed in different parts of the eastern United States. The meadow water which irrigation is practiced in these regions ranges from 10 to more than 100 inches annually. The practice of irrigation in desert regions is in the nature of an insurance against dry years. The

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probability of the occurrence of these in the eastern United States is shown in the following table* of rainfall months for the ten years from 1910 to 1919, inclusive:—

| States | Average Annual Rainfall | Number of | |
|--------------------------|-------------------------|--|--|
| | | Months in which more than 3 inches of rain | Months in which less than 3 inches of rain |
| Arizona, June | 30.59 | 25 | 100 |
| Idaho, June | 29.75 | 27 | 100 |
| Utah, June | 45.27 | 46 | 100 |
| Colorado, June | 22.55 | 62 | 100 |
| Nebraska, June | 30.75 | 61 | 100 |

(*) Six days needed until after a three-day period with less than 1 inch of rain.

The aggregate area of the projects is small and amounts to only a few thousand acres.

856. The Reclamation Service. "The financing of irrigation enterprises by the Federal Government through the Reclamation Service has been a wonderful stimulus. The total number of acres in which ditches have been constructed or are in process of construction in this way aggregates 1,000,000, in thirty projects distributed through seventeen States and involving a total expenditure of hundreds of thousands of dollars. These projects contemplate the irrigating of 10,272,460 acres of water.

*Williams, M. R. *Facilities and Need of Agricultural Irrigation in the Great Region*. U. S. D. A., Technical 1914, pp. 326-328.

Also, Tuck, A. F. *Irrigation in the West*. American Encyclopedia of Agriculture, p. 657. New York, 1915.

Almost everything of this sort was originated in 1916. Many of the ideas and plans involved are of stupendous size and necessitate feats of bold engineering. Often hydroelectric power is developed to keep current in the passage of the water from the reservoirs to the fields where it is to be used to grow crops.

III. Legal, economic and social effects of irrigation.—The practice of irrigation on an extensive scale has caused important changes in the construction of law¹ relative to water and property rights and in commercial and social organization.

Agriculture rights in streams and lakes under normal conditions, for purposes of domestic use, power, and transportation, must be modified in an arid country. The values of all real property depend largely on the supply of water for purposes of irrigation. The control and use of water becomes of the utmost public concern. Consequently the use of water for the purposes of growing crops takes precedence over use for all other purposes except domestic use. It needs every facility in the world where irrigation is extensively practiced, the state or the government has assumed controlling or a large measure of control over the water in all lakes and streams. The necessity of the use of water for irrigation has controlled

¹ Mead, R. *Irrigation Institutions*. New York, 1930.
Mead, R. *Irrigation Institutions in Different Countries*. American Encyclopedia of Agriculture, Vol. IV, p. 161. New York, 1931.

Flinn, H. H. *Particular Discussion of American Irrigation Problems*. American Encyclopedia of Agriculture, Vol. IV, p. 161. New York, 1931.

Flinn, H. H. *Socio-Economic Aspects of Irrigation*. American Encyclopedia of Agriculture, Vol. IV, p. 162. New York, 1931.

certain privileges, such as the principle of riparian domain, in securing and utilizing water. The provisions offer somewhat in detail, but in general agree in conferring the right to use water upon those persons who can first make the best use of it for the purpose of growing crops. Other rights in the use of water are largely subject to its use for irrigation. Further, the tendency is to attach the right to the use of water to the lands to which water each has value only as it is associated with the other. However, in the attachment of water from a particular source to any given acre of land, many difficult questions may be raised which must be decided by the larger principle of beneficial use.

A close economic dependence among the people and a high degree of social cohesiveness grows out of the practice of irrigation farming on a large scale. The fertile nature of the soil, the favorable climate, and the cooperation necessary to supply water for irrigation, leads to intensive methods of farming, to specialization in production, and to many cooperative enterprises, not only in agriculture, but also in associated industries in the same region. These intensive ranches and the close personal association involved present a high industrial and social standard in the community. Irrigation has been an efficient schoolmaster in the practices and value of cooperation in all sorts of enterprises.

194. *Division of Irrigation.*—Two main parts make up the practice of irrigation: the first is the provision of water, which is essentially an engineering problem; the second is the use of water on the land, which is an

¹ Wilson, H. M. *Irrigation Engineering*, p. 133. New York, 1905.

essentially an agricultural problem. It is important to maintain this clear distinction in dealing with the practice of irrigation, especially in its large aspects. The two functions are largely executed by different groups of men, and they involve widely different types of knowledge and skill. The expenditure of an irrigation system is effected, not of the water on the land in the production of crops.

(4). *Sources of water for irrigation.*—The practice of irrigation is dependent on some adjacent supply of water that may be diverted on to the land. It may be derived by (1) the diversion of streams flowing from well-watered regions; (2) the tapping of water on mountain slopes; (3) the regulation of the flow of streams by storage reservoirs; and (4) the utilization of underground water by means of wells. All these sources may require the construction of large and costly works, which are well exemplified in the structures built by the United States Reclamation Service and by the Egyptian government in the Nile valley. These hundreds of feet high and thousands of feet long, embanking millions of cubic yards of masonry and concrete, have been constructed for these purposes.

(5). *Canals.*—The conveyance of the water from the point of supply to the place where it is to be used necessitates further difficult engineering problems, which in some cases have entailed the construction of large tunnels under mountains and the development of large pumping and power plants as well as the construction of thousands of miles of main and lateral canals. In 1913 the length of main irrigation ditches in the United States was 835,000 miles, and of laterals 30,000 miles. As a rule the water is conveyed by gravity flow without pressure. Important

systems presented relative to the prevention of seepage, erosion, and evaporation. The least of water is moved from its source to the field but has been found to average 10 per cent, and its range from 0.55 per cent to as much as 61 per cent a mile with an average of about 6 per cent. The seepage water from canals may result in further loss by accumulating in low lands, where the evaporation, coupled with the addition of the soluble salts in the soil, causes injurious accumulation of alkali in the surface soil, and in extreme cases a swampy condition which destroys the value of the soil for agricultural purposes. In order to prevent seepage many kinds of lining and treatment of the walls of canals have been employed. Cement, timber in different forms, wooden frames, clay matting, oiling, application of tar, red oiling have been used. The need of a lining depends much on the nature of the formation through which the ditch passes. Silt is an excellent means of checking seepage. Where clear water is carried, the ditch must usually be lined, and the practice of lining canals in order to reduce seepage is increasing rapidly. Small and gravel permit much seepage and are easily eroded. They permit little seepage and is not easily eroded. The velocity of flow of water in canals should not exceed three feet a second. In large canals this will not permit a grade of more than six inches in a mile; in very small ditches a grade of from forty to fifty feet in a mile may be necessary to cause the same velocity of flow. A lining that is not subject to erosion, seepage

¹ Tull, R. P. *Vegetation and Drainage Investigations* (U. S. D. A., Office of Eng. Sta., Ann. Rept. 1904, p. 26). Also Mead, R., and Stevenson, D. A. *Design of Ditches and Drainways for Farm Drainage Systems*. Calif. Agr. Exp. Sta., Bul. No. 185, 1927.

with a channel that is deep in relation to its width, not only reduces seepage, but also, by permitting the rapid flow of water, reduces loss by evaporation.

At the form on which the water is to be used, it is distributed in small field intervals which are carried on the higher ground. Transverse siphon sumpage and sumpage ratios should here be taken. The sumpage ratio is based on the distribution of the water to the fields by means of underground pipes, with sumpages and valves at the points of discharge. The arrangement of the farm intervals must of course be determined by the topography of the land, since the water flows by gravity.

877. Preparation of land for irrigation. — The preparation of the land for irrigation depends on the method used to apply the water. Usually marked irregularities should be removed by smoothing the surface. Where any sort of basin method of irrigation is used, it may also be necessary to level the surface. Various types of sumpers and basins have been found useful for this operation. Mounds of the soil and raised bed culture is a growth of sage brush or other bushy vegetation, and of course this must be removed before smoothing operations can become effective.

878. Methods of applying water. — There are four general methods of applying water to the soil. These are (1) overhead sprays, (2) sub-irrigation, (3) flooding, and (4) furrows.

879. Overhead sprays. — By the overhead spray system (Fig. 78) the water is distributed by pipes under a pressure of force to spray nozzles and discharged from a series

¹ Parker, S. Methods of Applying Water to Crops. U. S. D. A., Yearbook 1909, pp. 261-265.

of water. Several types of nozzles are employed. The amount of water that can be applied is relatively small, and consequently the method is most clearly in broad use to supplement a rather high rainfall, in the growth of crops of large value. It is used in the growth of truck and small fruit crops near the large eastern cities.

The advantages of the system are:—

1. The water is conveniently applied at the desired point. 2. The system may be used on uneven land and without preparation of the surface. 3. There is no waste of land by ditches. 4. The application of the water is easily controlled by valves and by the movement of the pipes.

The disadvantages of the system are:—

1. The capacity is limited. 2. The cost is high for equipping and maintaining the plant, and for developing the pressure required to suitably distribute the water from the nozzle. 3. There is possibility of injury to crops whose water is applied on warm, bright days, since the water comes into contact with the foliage.

300. Sub-irrigation.—Sub-irrigation is the distribution of water from underground pipes. These are buried in the soil and perforated in such a way that the water finds an outlet and is distributed by the capillarity of the soil and by natural gravity flow. In greenhouses and where shallow-rooted annuals are grown, lines of drain tile are employed, the water flowing out at the joints. Continuous pipes having an open seam or perforations have been used. Another method employs a porous ceramic pipe which has a little above the supply pipe. The object of the above-mentioned method is to avoid the serious difficulty from the entrance of roots into the pipes. The pipes must have a very slight grade in order to insure a



Fig. 137 - Diagram of a vertical structure, showing a vertical shaft or column, a horizontal arm or beam, and a cross-section of the structure. The diagram is labeled with various parts and numbers, including 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239, 240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 266, 267, 268, 269, 270, 271, 272, 273, 274, 275, 276, 277, 278, 279, 280, 281, 282, 283, 284, 285, 286, 287, 288, 289, 290, 291, 292, 293, 294, 295, 296, 297, 298, 299, 300, 301, 302, 303, 304, 305, 306, 307, 308, 309, 310, 311, 312, 313, 314, 315, 316, 317, 318, 319, 320, 321, 322, 323, 324, 325, 326, 327, 328, 329, 330, 331, 332, 333, 334, 335, 336, 337, 338, 339, 340, 341, 342, 343, 344, 345, 346, 347, 348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 365, 366, 367, 368, 369, 370, 371, 372, 373, 374, 375, 376, 377, 378, 379, 380, 381, 382, 383, 384, 385, 386, 387, 388, 389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 417, 418, 419, 420, 421, 422, 423, 424, 425, 426, 427, 428, 429, 430, 431, 432, 433, 434, 435, 436, 437, 438, 439, 440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 452, 453, 454, 455, 456, 457, 458, 459, 460, 461, 462, 463, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475, 476, 477, 478, 479, 480, 481, 482, 483, 484, 485, 486, 487, 488, 489, 490, 491, 492, 493, 494, 495, 496, 497, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 508, 509, 510, 511, 512, 513, 514, 515, 516, 517, 518, 519, 520, 521, 522, 523, 524, 525, 526, 527, 528, 529, 530, 531, 532, 533, 534, 535, 536, 537, 538, 539, 540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 552, 553, 554, 555, 556, 557, 558, 559, 560, 561, 562, 563, 564, 565, 566, 567, 568, 569, 570, 571, 572, 573, 574, 575, 576, 577, 578, 579, 580, 581, 582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593, 594, 595, 596, 597, 598, 599, 600, 601, 602, 603, 604, 605, 606, 607, 608, 609, 610, 611, 612, 613, 614, 615, 616, 617, 618, 619, 620, 621, 622, 623, 624, 625, 626, 627, 628, 629, 630, 631, 632, 633, 634, 635, 636, 637, 638, 639, 640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 661, 662, 663, 664, 665, 666, 667, 668, 669, 670, 671, 672, 673, 674, 675, 676, 677, 678, 679, 680, 681, 682, 683, 684, 685, 686, 687, 688, 689, 690, 691, 692, 693, 694, 695, 696, 697, 698, 699, 700, 701, 702, 703, 704, 705, 706, 707, 708, 709, 710, 711, 712, 713, 714, 715, 716, 717, 718, 719, 720, 721, 722, 723, 724, 725, 726, 727, 728, 729, 730, 731, 732, 733, 734, 735, 736, 737, 738, 739, 740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 752, 753, 754, 755, 756, 757, 758, 759, 760, 761, 762, 763, 764, 765, 766, 767, 768, 769, 770, 771, 772, 773, 774, 775, 776, 777, 778, 779, 780, 781, 782, 783, 784, 785, 786, 787, 788, 789, 790, 791, 792, 793, 794, 795, 796, 797, 798, 799, 800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 816, 817, 818, 819, 820, 821, 822, 823, 824, 825, 826, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 858, 859, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 883, 884, 885, 886, 887, 888, 889, 890, 891, 892, 893, 894, 895, 896, 897, 898, 899, 900, 901, 902, 903, 904, 905, 906, 907, 908, 909, 910, 911, 912, 913, 914, 915, 916, 917, 918, 919, 920, 921, 922, 923, 924, 925, 926, 927, 928, 929, 930, 931, 932, 933, 934, 935, 936, 937, 938, 939, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 952, 953, 954, 955, 956, 957, 958, 959, 960, 961, 962, 963, 964, 965, 966, 967, 968, 969, 970, 971, 972, 973, 974, 975, 976, 977, 978, 979, 980, 981, 982, 983, 984, 985, 986, 987, 988, 989, 990, 991, 992, 993, 994, 995, 996, 997, 998, 999, 1000.

KEY WORDS: PROPERTIES AND CHARACTERISTICS

uniform distribution of water. They operate under little or no pressure. The system has a number of advantages, but in practice there are usually more disadvantages than advantages. The advantages are:

1. The system is permanent.
2. It is economical of water.
3. There is no injury to the physical properties of the soil.
4. There are no obstructions at the surface.
5. The deep rooting of crops is encouraged.
6. There is very little expense for operation of the distribution of water.
7. The accumulation of salts/solids on the surface of the soil by evaporation is reduced.
8. The system may sometimes be used as a means of drainage also.

The disadvantages are:—

1. There is a strong tendency for the pipes to be clogged by the entrance of roots, especially where perennial crops are grown. The porous-pipe method of discharging water is designed to reduce this difficulty.
2. The slow lateral capillary diffusion of water in dry soil makes it necessary to install the lines of pipe near together, which entails heavy expense.

The method is best adapted to shallow-rooted annual crops, and best adapted to orchards. The seepage of water from the pipes attracts the growing roots, which are likely to enter the pipes, break up into many small pieces, and clog the system.

There are soil conditions under which this method is especially useful. Where the soil is a porous sand or gravel washed at depth of four feet or less by a rather impervious stratum, the water may be distributed rapidly from the pipes so that it accumulates on the hard substratum and saturates the soil, the pipes being quickly emptied. There is then no tendency for the roots to enter the pipes, and the porous nature of the soil permits

the pipes to be placed several miles apart, thus reducing the expense of installation.

Sub-irrigation sometimes occurs naturally under conditions similar to those just described, when water is supplied from springs or by seepage. Where it can be employed, sub-irrigation is the ideal method of applying water to the soil.

601. *Methods most used in arid regions.*—The two methods previously used to apply water to the soil under arid conditions are by furrows and by flooding. The land must generally be prepared in some method for either of these methods, by smoothing, or leveling the surface, throwing up levees, or constructing distribution furrows. It is a fortunate fact that the subject in arid regions is almost as facile as the soil, and therefore grading can be practiced with impunity. Both methods have a large number of variations in detail to adapt them to particular soils, topography, or crops.

The chief factors determining the choice between flooding and furrowing are (1) the nature of the crop, (2) the character of the soil, (3) the nature of the land, and (4) the quantity of water available.

602. *Flooding.*—Flooding is especially employed (1) where the crop occupies the whole area, such as in grainlands and meadows, (2) where the soil is of uniform fertility and does not have seriously no drying, (3) where the surface is relatively flat, and (4) where the supply of water is relatively large.

The advantages of this method are:—

1. The handling of water is easy.
2. There is scarcely no ditching.
3. The necessity of turning up the crop is avoided.
4. The method is especially suited to certain crops.

that grow in standing water, such as rice and cranberries.

Its disadvantages are:—

1. A large quantity of water is required.
2. Over irrigation, with consequent seepage and dilution from nitrate, is likely to occur.
3. On heavy soil, puddling and churning of the surface soil results from lack of tillage.
4. Some crops are injured by direct contact with water.
5. The cost of levelling and of construction of levees is large.

There are two main types of flooding. In the first the water is turned into level checks or blocks, where it stands until it is absorbed by the soil—called commonly check-flood flooding. In the second type the water is distributed in a moving sheet or a series of small rills, from which supply ditches—called open-field flooding. This method is used only where there is a moderate slope to carry the water.

In check-flood, or check, flooding, the land is divided into blocks, each having a level surface and surrounded by a levee. The size of the checks, their shape, and the height of the levees is determined by the contour of the land. On a slope they may be very irregular. Level checks of one to three acres are most successfully irrigated, but areas of twenty or more acres have been flooded in one block. A flow of five to seven acre-inches of water is necessary in order to make the system thoroughly successful. One man can irrigate from five to twenty acres a day, depending on the size and form of the checks. The levees may be permanent, as is usually the case especially in mudflows, or they may be thrown up for each application of water. The permanent levees may

to bend and turn so that they will not interfere with burrowing. The method of feeding is falling into three.
A phase of direct feeding is the basin method of ingesting sediments, in which small, shallow basins are formed around each tree and separated from the trunk by a diaphragm.

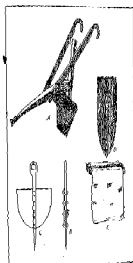


FIG. 12. Diagrams illustrating the feeding mechanism. (A) shows the feeding structure in the feeding process. (B), (C), and (D) show the feeding structure in the feeding process. (E) shows the feeding structure in the feeding process. The diagram illustrates the feeding mechanism of stomatopods and dasypanulus.

of earth to prevent injury to the growing weed. This method is used rather extensively throughout the arid regions.

In the overhead, or flood, method, the water is supplied in ditches which are carried across the contour of a moderate grade, and at intervals the flow is interrupted by a control dam or other obstruction, and forced to flow over the lower bank, from which point it is distributed down the slope and over the field in numerous small channels. Any surplus water is collected in a ditch at the lower side of the field. In this method of applying water constant attention is required to grade the flow and prevent erosion. One man can irrigate from five to ten acres in a day. This method is used in irrigating grainfields and stocking arid-land and in saturating the soil in preparation for a crop.

8th. Furrows.—In the furrow system of irrigation the water is led out from the supply ditch on the upper side of the field into small, parallel furrows extending down or across the slope at a considerable grade. This system is used for cultivated field and garden crops, and to a large extent in orchards. The rate of flow of water in the furrows should not exceed one to two feet per second, depending on the nature of the soil. This permits a wide range of grade, from 2 to 10 per cent, where the head of water is only a fraction of a second-foot in each furrow. The flow on a given slope may be regulated by the head of water and is determined by the permeability of the soil. On heavy soil a small head and a steep grade may be employed, on sandy soil, which soaks easily, a low grade and a large head of water is used. The length of furrows that may be employed depends on the nature of the soil and the head of water available. The water is distrib-

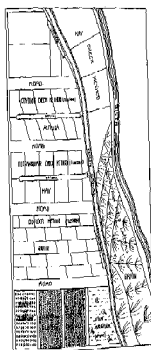


Fig. 7B.—Photo of irrigated furrows showing the methods of printing different signs and the arrangement of the irrigation wheels for applying the water under the different conditions.

ward from the furrows by percolation and by capillary movement. Percolation causes the accumulation of water under the edge out of the furrows; capillary movement distributes the water laterally as well as downward.

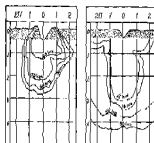


FIG. 78.—Diagram shows the relative rate of movement of water from irrigation furrows into dry areas (left), and wet areas (right), after different periods of time.

and its rate determines the distance between the furrows. The downward¹ movement is much more rapid than the lateral movement, and both are very irregular, depending on the nature and structure of the soil. Ordinarily the furrows are relatively close together, to give greater uniformity in distribution. In corn, potatoes, beans, garden vegetables, and crops of similar structure, a furrow is placed in each row, or at least in every other row as is

¹ Wilcox, L. A., and McLaughlin, W. F. The Movement of Water in Irrigated Soils. *Trans. Agr. Exp. Sta., Bul. No. 215*. 1913. Also, *Engineering, N. H.* Distribution of Water in the Soil in Furrow Irrigation. U. S. D. A., Office Exp. Sta., Bul. No. 220. 1908.

strengthen the race in strengthening, in order to permit harvesting.

In orchard culture two or more farmers are placed between each two rows. When the young trees a farmer is placed on either side at a distance of about two feet, this distance being increased as the trees increase in size. The farmers are temporary and are usually replaced when such application of water, or the establishment of a soil which is necessary in order to prevent excessive loss of water by evaporation.

104. Size and form of furrows. - In shape the furrows should be relatively narrow and deep. When it comes to the form of the furrows, (1) it should be made fairly, both in the form and rate of work; (2) the surface is exposed to compression; and (3) the surface width is more easily maintained. (See Fig. 60.) Below and outside a deep trench 4' at its to eight inches is most

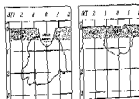


FIG. 60.—Diagram showing the relative values of water into the soil from a deep (A) and a shallow (B) irrigation furrow. Note the relative values of water into soil in the two cases. A deep water and deep irrigation furrow will be the most effective at certain.

¹ Perkins, G. *Suppression of Water in Irrigation and Water Regeneration of Crops*. U. S. D. 4, (The Dry Soil, Vol. 10, No. 177, 1947).

efficient, and the bottom of the furrow should extend well below its base. This will allow the water to diffuse laterally equally, and the deep dry moils reduce the extent to which the surface becomes solid, thereby conserving moisture and retarding the accumulation of salts at the surface.

The application of water to the soil in irrigation must be guided by the principles elucidated in the discussion of the physical properties of the soil, and its relation to moisture and its control.

536. Units of measurement.—The measurement of water in irrigation practice involves the use of units of volume and pressure. By the head is understood the volume of water applied in the unit of time. The flow of water in canals is usually stated in units of flow per unit of time, that is, the number of cubic feet per second, called the second-foot. Frequently the term second-foot is applied to the volume of water that would result from a flow of that rate throughout the season. A smaller unit is the miner's inch, a term derived from mining practice, which refers to the quantity of water that will flow out of an orifice one inch square under a constant pressure which varies in different states from a flow to an eight-inch head above the top of the orifice. Like the second-foot, the flow is frequently rated by the square. The pressure is proportional to the depth, or head. It is commonly stated in pounds per square inch. A column of water ten feet in height exerts a pressure of approximately 4.33 pounds to a square inch.

In the field, water is commonly measured in terms of depth over an acre. An acre-foot is the quantity of water that will cover an acre one foot in depth. An acre-inch is one-twelfth of an acre-foot. These are very convenient

stems because of their delicateness and relation to the
 common method of diving animals. Usually an fish is a
 foot of water below the depth over which it
 swims. Various mechanisms are employed for increasing
 water in irrigation position. The contents of these
 are the web and the flaps. (See Fig. 31.) The web is



FIG. 31. — Fish showing the web and a typical web with the
 by the flow of water in the water.

a simple device to give the fish a definite mass action
 and to act in the movement of the depth and there-
 fore the volume of flow. It is usually a well-defined web,
 of a standard shape and used in a great variety of
 shapes as shown from which the depth of water and
 the velocity are used. The remaining part, frequently
 termed a mouth, is used for controlling the flow of water
 from an active water flow condition. The fishlike
 mouth, developed in fish, is most generally adapted for
 the purpose. Small animals are fitted by a knowledge

1. Carpenter, L. C. The Mechanism of the Mouth of Fishes.
 Columbia Univ. Press, Vol. 10, 100, 100, 100, 100.

diverted inserted into the current, which diverts a definite portion of the stream. This is called a *divulver*.

406. Amount of water to apply.—The amount of water to apply to the soil at any one time depends on (1) the nature and condition of the soil, (2) the supply of water, (3) the crop, and (4) the season. In the main, enough water should be applied to sufficiently saturate the soil to a depth of one foot and to loosen the soil consistent to a depth of three feet. A fairly dry, firm-textured soil will effectively take the largest irrigation. Some crops are more sensitive to water at one period of growth than at another. Potatoes should mature in a rather dry soil. The application of water at a single irrigation should ordinarily be from four to eight inches. In very hot weather it may be reduced to two or three inches. In late fall or early spring, when the soil is unsaturated, the application may be relatively larger provided the soil is dry.

Excessive irrigation is to be avoided. While the total yield increases with increase in the application of water up to the saturation point, the unit production decreases! The following table, calculated by Wallace from actual yield of wheat, illustrates this point.

| | Yield (bushels) or Tons per acre | | | | |
|---------------|----------------------------------|----------|----------|----------|----------|
| | 1 inch | 2 inches | 3 inches | 4 inches | 5 inches |
| Great Goshawk | 47.21 | 91.43 | 130.19 | 166.16 | 226.11 |
| Small Goshawk | 43.22 | 209.8 | 195.03 | 224.9 | 179.9 |

¹Williams, J. L., The Production of Dry Matter with Different Quantities of Irrigation Water. Utah Agr. Exp. Sta. Bul. No. 118, 1912.

Small applications of water are relatively most efficient. Up to the limit where injury results, the more concentrated the soil solution, the larger is the yield of crop.

627. *Time to apply water.*—The best time to apply water depends to a large extent on the nature and habits of the crop. Ordinarily the soil should be thoroughly moistened at the time of planting, in which case the application will have been made before filling the ground. For sugar beets and other crops planted in rows, it is permissible to irrigate immediately after sowing. The direction of a crop is to be avoided. After planting, water may be applied at intervals of two or four weeks, or when the soil has reached the stage of dryness at which sluggish capillary movement ceases. The experienced irrigator however very persistent in maintaining this condition. For grain and forage crops, the soil should be well moistened when the crop approaches maturity. For alfalfa, irrigation may be either shortly before or just after harvest with good results. For root crops a relatively dry condition of the soil at maturity is preferred. The same is true for trees, and the large application of water late in the growing season is especially to be avoided, because the new wood growth is likely to be winter-killed. Irrigation in spring, especially at blossoming time, is to be avoided because it interferes with the setting of fruit. One or two thorough irrigations in a season are usually sufficient for the growth of trees. Small fields should have plenty of water at the maturity of the crop. Where water is available in late fall and in winter, it may be applied to the soil and stored there for use during the following season. Irrigation at that time is

¹ Wilcox, J. A. The Science of Water Irrigation in New. Utah Agr. Exp. Sta., Bul. No. 304, 1908.

have shown that moisture may be effectively stored in the soil to a depth of more than eight feet and be readily used by crops the next season. The total amount of water to be applied depends on many things. The following factors affect the duty of water: (1) character of the crop; (2) climate; (3) texture and structure of the soil; (4) depth of the soil; (5) fertility of the soil, including the total amount of soluble material; (6) kind of tillage practiced; (7) thickness of planting; (8) season when the crop grows; (9) frequency and method of applying water; (10) amount and time of applying water. A fertile soil and a large and rapid growth of the crop go with economy of water.

Many of the above factors, such as thickness of planting, tillage practice, and manner of using water, determine the loss from the soil that has no direct relation to the crop. The total amount of water to be applied¹ in irrigation should range from five to twenty inches, with the tendency toward the lower figure. This means a duty of 200 to 75 acres a stand-still for a season of sixty days. From one to five applications of water are usually made. The larger the plant and the deeper the root system, the larger the individual application of water may be, and the fewer the number of applications.

80. Conservation of moisture after irrigation.—The conservation of moisture applied by irrigation should be provided for whenever practicable. Crops planted in rows should be mulched as soon as the soil is dry enough not to puddle. An irrigation above, when the former method is employed the farmers should be kept, so that only a small part of the surface soil will be wet. Complete

¹Walton, J. A. Principles of Irrigation Practice, Chapter XVII. New York, 1904.

with this, a mulch of dry soil from four to eight inches deep should be maintained. This is a protection against too high a temperature in moist soil superheated by shade, as well as against loss of moisture. The surface of the soil should be kept as nearly level as possible.

Crops that are not planted in rows, such as grain, may be cultivated with a fine tooth harrow until they reach a height of four or five inches to a foot, at which stage composition from the soil is largely prevented by the shading of vegetation. If it is to be stored this cultivation must begin as soon as the seedlings appear above the surface, in order that the roots may be forced deep into the soil. Then the top may be mulch treated with soil. Little injury to the plant, and that injury appears to be more than overbalanced by the shading of the plant. By prompt and thorough tillage following irrigation, very much may be done not only to conserve soil moisture but also to prevent the accumulation of alkali at the surface by evaporation.

838. Sewage irrigation.—A phase of the general practice of irrigation in the application of sewage¹ to the land for purposes of crop production. This supplies plant food as well as water. The fecal content, however, is relatively small, being about two parts in one thousand, of which one-half is organic and one-half is inorganic material. In European countries sewage irrigation is extensively employed now, while in the United States this practice has not been largely followed. The city of Boston has carried out extensive experiments, and the city of Los

¹ Butler, H. W., and Butler, M. W. *Sewage Disposal in the United States*. New York, 1904. Also Butler, H. W. *Sewage Irrigation*. U. S. Geol. Survey Water Supply and Irrigation Paper, No. 3, vol. 22. 1907 and 1908.

Angeles has a large farm irrigated with sewage water. The same general principles govern in the use of water as in normal irrigation practice, except that the soil may become clogged and bad from the accumulation of solid material, especially where the idea of *diagonal* row-shedding that of efficient use. This practice is most chiefly for the production of hay and forage.

DRY-FARMING

The water supply for irrigation is sufficient for only a small part of the world's surface which needs such treatment. The remainder of this vast area of land having a deficient rainfall must be utilized, if at all, by the most scrupulous and careful conservation and use of the natural rainfall. The growth of crops without irrigation under such conditions is termed *dry-farming*.¹ It is merely an intensified form of the methods which are recognized as good practice to conserve moisture in some local regions.

Dry-farming is based on the principle that the production of dry matter in crops requires only a small part of the water which may be used in any way or another in its growth, and that a large part of this water is lost by evaporation.

¹Williams, J. A. *Dry Farming*. New York, 1910. (Agricultural Extension Group, U. S. Department of Agriculture.)
 Macdonald, Wm. *Dry Farming*. New York, 1910.
 Campbell, R. W. *Soil Culture Manual*. Lincoln, Nebraska, 1907.

Chubb, R. C. *Dry Farming in the Great States West*. U. S. D. A., Yearbook, pp. 451-468. 1907.

Briggs, L. C., and Shantz, H. L. *The Water Requirement of Plants: Investigations in the Great Plains in 1919 and 1921*. U. S. D. A., Bur. Plant Ind., Bul. 284. 1923. Also, *The Water Requirements of Cereals. A review of Literature*. U. S. D. A., Bur. Plant Ind., Bul. 285. 1923.

been done, by seedings, and especially by cover-crops, without performing any real service to the plant.

410. *Problems in dry-farming*.—The problem of dry-farming may be divided into three groups: (1) the maintenance of such a condition of the soil at all seasons of the year as will insure the complete absorption of the rain and snow-fall, (2) the conservation of the stored moisture by appropriate methods of tillage, (3) the selection of drought-resistant crops and of varieties adapted to the small use of water.

411. *Storage of water in the soil*.—In different regions the rainfall occurs at different seasons. A loose, open condition of the surface soil should be maintained during that period. This may require deep plowing, and if the rainfall is supposed to may include windrowing. Where the precipitation comes so soon, the surface should be roughened so as to prevent drilling, in order that the resulting water may be uniformly absorbed by the soil. Fall plowing is so important here where much of the precipitation comes in winter and the soil is compact. Another reason for the prohibition of a ridge system is to reduce erosion by the high winds which frequently occur in winter in dry-farming regions and which cause the serious removal of the soil. The roughened surface impedes the wind movement, and the moist soil at the root of the ridges resists erosion.

412. *Conservation of moisture*.—The conservation of the moisture in the soil involves two things—no increase in the capacity of the soil, and the prevention of evaporation. Where the rainfall is low, the deep subsoil is usually very dry. The rainfall penetrates to a limited distance from the surface. Having reached the subsoil so that the rainfall is absorbed, the moisture is so compact

the substratum as much as possible by clings in order to increase its capillary capacity. The need of this treatment, of course, depends on the nature of the soil, and is not always the most favorable. It is undesirable that this packing should extend to the surface. Following the plow, the land is frequently worked down with a subsoil packer, an implement of considerable weight, made up of opposite rims that press the soil together and at the same time leave a ridge on the surface. By acting on the lower part of the furrow instead of on the surface, the packer brings it into closer contact with the subsoil and thereby establishes better capillary connection.

After thorough packing of the main part of the furrow, a final touch is maintained on the surface. This should be of medium depth in the season when rains are likely to occur, and of somewhat greater depth during the dry period. Two or three inches is usually a sufficient depth.

Various applications of the principle of working may be employed. Land may be disked before plowing in fall or spring, to break residues until the plowing can be done. As soon as a crop is removed, the land should be plowed or disked and worked down to a good finished surface. Land should not be allowed to stand uncultivated for any considerable time after harvest. All annual crops should be kept thoroughly mulched. Much may be done to conserve water in grain and hayfields by clings. The same principles apply to the pastures that are used on irrigated land. Special revolving tined implements have been devised to loosen up the surface soil under such conditions.

* 413. Alternate sowing.—When the rainfall is too light it is almost certain to prevent the production of a profit-

able crop, it is sometimes the practice to collect and store the middle of two seasons in the soil. This is the system of alternate-year cropping. In the intervening year the soil is carefully followed and worked, to hold the stored moisture. Thus such long-term storage of available moisture is possible has been clearly demonstrated¹ under dry-farming conditions, and also in the study of irrigation problems. An arid or a semiarid climate is especially favorable for the formation and maintenance of an efficient stored moist, and the occurrence of dry earth in the lower subsoil permits moisture to be stored and retained in large quantities within reach of the roots of crops. It is believed by some persons that the practice of fallowing in alternate years is very destructive of capillary water in the soil, and that it may be better to grow a grain-mature crop in that period to be stored water. It is questionable whether the loss of water may not be a serious objection to this.

84. Drought-resistant crops.—For growth under dry-farming conditions, crops are produced which have a low moisture requirement, which are not seriously affected by severe drying, and which have a fairly deep root system. The sorghums come in the first class and also fulfill the second requirement. Corn is fairly satisfactory. Wheat, barley, and alfalfa are frequently drier crops. Drought-resistant varieties of these crops are being sought. A rotation is desirable which exposes the soil as little as possible to exposure, and permits continuous working with the minimum of plowing.

¹ Adkins, A., Perkins, H. O., and Wheeler, L. P. *Dry Farm Moisture Studies*. *Monthly Rep. Agr. Sta.*, Ind. St. 1911. Also Eyer, W. F. *Drought Moisture in the Soil*. *Nebraska Agr. Exp. Sta.*, Bul. No. 114. 1915.

III. SOILS: PROPERTIES AND MANAGEMENT

III. Soils associated with dry-farming.—Dry-farming is often closely associated with irrigation, being practiced on the heavier soils where the water-storage capacity is large and where the practice of irrigation is most difficult. Successful dry-farming requires an annual rainfall of at least fifteen inches, and twenty inches is much safer as a basis for the practice. A general principle to be observed in dry-farming is that the thinner the soil moisture supply, the lighter should be the rate of seeding. Wheat, for example, may be seeded at the rate of only twenty pounds



FIG. 12.—Areas of western United States where dry-farm wheat is commonly practiced.

to the soil. The crop will stand out strongly and adjust itself to the moisture supply. Under dry-land and irrigation farming, crops to a mile past reach deeper than in humid soils.

816. Extent of dry-farming.—In the United States many thousands of acres in the Great Plains region, in dry semiarid northwestern valleys, and in the Pacific Coast States, are now being cropped under systems of dry-farming (see Fig. 82). Partly, the practice is becoming to be followed wherever conditions are definitely in all parts of the work where similar conditions prevail. The large open areas of land and the dry climate in such regions have encouraged the employment of large power equipment in planting and harvesting the crops, especially wheat. In parts of California machines are used which cut, thresh, and stack the grain in one operation.

The study of the principles on which dry-farming is based, together with the acquisition of their practice, may be expected to bring large areas of land, now substantially worthless, to a noticeable degree of productivity. The tendency in the practice of both dry-farming and irrigation is toward the more efficient use of water for purposes of crop production, and its approximate actual requirements of the plant is the subject of water.

In both cases the fundamental principle in the storage, conservation, and use of water by plants must be observed, as well as also regarding the application of these principles according to the soil, the crop, and the nature of the water supply.

CHAPTER XXX

THE SOIL SURVEY

The function of the soil survey is to investigate the nature and occurrence of soils in the field. The soils are classified into areas having approximately the same crop relations and tillage properties. The location of the areas of each kind of soil is represented on charts or maps, and their character and kind economic and agricultural relations are described in printed reports.

§17. The classification¹ of soils by survey.—The occurrence of differences in the tillage and material re-

¹ Klassifikation, Benennung, und Vorkommen der Bodensorten.

² Vorträge der zweiten Internationalen Agropedologischen Konferenz. (Proceedings of the Second International Agropedological Conference, Stockholm, October 7, pp. 334-335. (German paper.) 1911.)

³ Report on Soil Classification. Proc. Amer. Soc. Agron., Vol. 4, No. 4, pp. 281-291. 1914.

⁴ Mappes, A. G. The Pedological Classification of Soils. Proc. Amer. Soc. Agron., Vol. 4, pp. 28-29. 1911.

⁵ Mather, C. F. Soils of the United States. U. S. D. A., Bur. Soils, Bul. No. 1, pp. 1-44. 1912.

⁶ Gilkey, O. D. A Study of the Soils of the United States. U. S. D. A., Bur. Soils, Bul. No. 1, p. 134. 1912.

⁷ Link, A. D., and Russell, R. J. Soil Surveys and Soil Analysis. Jour. Agr. Sci., Vol. 1, Part 2. 1911.

⁸ Pringle, M. The Genetic Classification of Soils. Jour. Agr. Sci., Vol. 3, pp. 41-45. 1910.

⁹ Beeson, W. E., Chubb, G. J., and Wilson, G. W. The

requirements of soils, their crop relations, and their agricultural value make necessary the determination of the properties of the soil that are chiefly responsible for these differences, and their arrangement into an orderly scheme of classification. The aim is to divide the land into areas of approximately the same general character. This scheme is largely an expression of those properties of soils that make differences in their crop relations and management. It is evident that differences are numerous and varied, and that some have greater significance than others.

Soils may be classified from many different points of view. The basis may be purely geological, purely physical, or almost entirely climatic. Any one of these alone is likely to be inadequate for the purposes of the geobotanist. The viewpoint of the agricultural soil survey should be such as to secure unity in the crop relations of each distinct area of soil recognized.

The system of classification is one most easily as a basis some combination of the groups of properties enumerated above. The combination selected has differed in different parts of the world, depending on the training

Principal Soil Areas of Iowa. *Iowa Agr. Exp. Sta. Bul.* 33, 1905.

Meyer, O. A. The Soils of Tennessee. *Tennessee Agr. Exp. Sta. Bul.* 38, 1905.

Swenson, C. W. The Eastern Soil Survey. *Dep. Agr. and Natural Resources, Ed. Agr. Exp. Sta.* pp. 17-22, 1907.

Swenson, C. W., and Pettit, J. H. The Fertility of Illinois Soils. *Illinois Agr. Exp. Sta. Bul.* 101, 1902.

Full, A. D., and Stewart, R. J. Report on the Agricultural and Forest Land Survey of Kansas. *Trans. Ed. Agr. and Mechan. Eng.* London, 1911.

Kennard, A. B. Soil Survey as Related to Geology. *N. I. Ed. Agr. Bul. Agr. Exp. Sta.* pp. 10-100, 1908.

of the picture by whom the survey was prepared, and the kinds of soils and crops with which he dealt. Some persons have used the vegetation,¹ especially the native vegetation, as a means of classifying soils. Where this is present it is an excellent means of identifying differences, and persons as well as others have always made use of the vegetation growing on a soil to detect variation in its cropping capacities. Unfortunately the vegetation, whether native or introduced, being a result of natural causes, affords information regarding the properties of a soil only when the correlation has been worked out. Further, the native vegetation is now seldom present in well-settled areas, so that it is inadequate as a general means of classification, though very useful for some purposes of comparison.

613. Factors employed in classification. — In classifying soils, four primary and two secondary factors are employed. The former group deals entirely with the soil itself; the latter group deals with the climate or the situation in which the soil is placed. The situation exerts an influence on the crop value and on the properties of the soil. The factors, beginning with those of the smallest range of occurrence, are as follows: (1) texture, (2) special properties, chiefly chemical, (3) kind of material from which the soil was formed, (4) agency of formation, (5) humidity and precipitation, and (6) normal and mean temperature.

The soil type is the unit of classification, and may be defined as an area of soil that is essentially alike in all the above characters.

¹ Hilgard, D. W. *Soils*, Chapters XXIV, XXV, and XXVI. New York, 1900.

619. Texture—the soil class. Of all the properties of the soil, the one which is most apparent and which exerts the most direct influence on the plant is the texture, or fineness of division, of the soil particles. Is it a clay, a silt, a sand, a gravel, or some combination of these? Is it sticky, or is it free from stickiness? The texture is the first property made use of in classifying soils. This division based on texture is called the soil class. It is a purely physical division, and does not recognize any chemical or other differences in the soil except as such differences may occur between coarse and fine materials.

620. Soedal properties—the soil series.—Soils of different texture may be alike in other properties. They may be all red, all black, or all yellow. They may be well drained or poorly drained. Such a group of soils of different texture, but alike in all other properties constitutes a soil series. The properties by which the soil series is recognized are (1) color, which is predominant in the upper part, (2) content of organic matter, (3) natural drainage, (4) content of lime carbonate, (5) chemical composition, and (6) arrangement of the soil in the region. Any one or a combination of these properties may identify an area of soils. Such an area would constitute a soil series. These properties permit the recognition of chemical differences quite as much as physical differences of the soil in mass.

If it were possible clearly to identify all the properties that may be recognized in the series and class divisions, there would be no need of employing other factors in the classification. Such a clear identification, however, is only partially possible, and is further limited by the conditions under which the soil survey must be carried out in the field. Many of these properties are of such

as indicate nature that they must be recognized by inspection. However, they are connected with the origin and mode of formation of the soil, and therefore the use of these factors in the classification is justified so as not to repeat what scientific field classifications.

321. *Source of material*—the soil groups.—The soils of a region may be similar in many properties because they have been derived from the same kind of rock. They may be similar also because they have been derived from the same nature of different rock materials. As a result of the many kinds of rocks and the different proportions in which they may be mixed, many groups of soil series may be recognized. Some of the commonest groups of soils identified with these differences are well soil, heavy crystalline rocks, shaly, sandstone, and limestone.

322. *Agency of formation*—the soil profiles.—The way in which a rock formation has been broken down and the weather brought to its new resting place affects both the chemical and the physical nature of the resultant soil. The six groups of forces that have been predominant in the formation of soils are: (1) weathering, or the decay and disintegration of rocks in place, forming a residual soil; (2) biological processes, which transform matter and give rise to humus soils; (3) water in solution, rains, and oceans, which remove, transport, and again re-forming materials, and which impart to soils deposits a distinctly stratified arrangement; (4) glacial phenomena, especially so regarding wind, which carries an extensive and sorting action similar to that of water but with a very much smaller range in the nature of the debris formed, and with a type of stratification also different from that formed by water; (5) glacial, or the action of continental masses of ice, the deposits from which are

accordingly. Intermingling is random and we without sorting or stratification except as the action of wind and water may have combined with the action of the ice; (8) gravity, or the slow creep of material on slopes, which is a minor agency of soil formation (see Chapter II).

226. *Climate.* Soils owe their origin to the operation of one or more of the forces named above. Usually none of these agencies is predominant and gives specific character to the soil. The elements of climate have been used in the practical classification of soils in only a small degree, since the inherent properties of the material in these divisions are usually distinct enough to make separation easy. The excessive accumulation of the middle salts known as alkali is associated with a low rainfall, and other chemical and physical properties are connected with aridity. These main divisions in humidity and precipitation may readily be made, namely, (1) *lunatic*, (2) *semi-lunatic*, (3) *arid*. The exact precipitation limits of these divisions depend on the temperature relations and the time and manner of occurrence of the precipitation.

In a valid system of soil classification the temperature relations of the soil would be recognized, but this division is seldom important in any single country.

226. *The practical classification of soils in the United States.*—As practiced in the United States, the classification of soils¹ has disregarded the climatic factor and has usually combined the kind of rock and the agencies of formation as a single basis of separation of soils, designating the climatic resulting character as a soil profile. In some cases one element of formation is dominant and

¹ Kricheldorf, C. P., Bennett, H. H., Lapham, J. E., and Jones, M. H. *Soils of the United States*. U. S. D. A., Bur. Soils, Bul. 96, p. 85. 1923.

in other areas another element is dominant. To this extent the classification deviates from the ideal system outlined above.

465. The soil type and series. These designated and named. — The two preliminary divisions of soil are the soil type and the soil series. The soil type is the unit of field study and classification, and corresponds to a species of plant or animal in biological classification. It includes all those areas of soil that are essentially alike in all properties — texture, color, chemical nature, structural properties, sources of material, and mode of formation. In other words, soils of the same type are so nearly alike no field identification will mistake. The soil series is a group of types differing only in the texture of the different members. This may be said to correspond to the genus in biological classification.

A name is given to each series of soil for purposes of easy identification, and in this sense the classification is aided, thereby fixing the identity of the type. For example, the Miami series includes certain light-colored, fine-textured, glacial soils of the East-Central States. The Hagerston series includes certain light brown to reddish residual limestone soils, found in the Virginian region of Kentucky and adjacent states. The Norfolk series includes brown yellow, marine-deposited soils of the coastal plain of the Atlantic and Gulf regions. (Soil names would refer to a particular texture of any of these series, as the Miami clay loam, for example, they specifying the type name of a soil, which is made up of the series name and the class designation.)

The manner possible to be used for the series designation some geographical name in the region where the soil is first classified or is best developed. The word

Almond is taken from the Almond River in southwestern Ohio, where the Almond series was first recognized.

The name of a proper growth series and a descriptive class name is most widely used in the United States to identify soil type. It gives a specific identity of the soil in its situation and in all its properties.

Hudlow¹ has proposed and used the Dewey Library System of numerical naming of soils, by which each property is given a fixed series of numbers and the classification number is obtained by combining the numbers that represent its properties. Whole numbers are assigned to important and definite soil types, and decimals are used for related types possessing some distinct variations. For example, 451.2 represents a glacial soil made up of broken loam on silt. While the numbering system of designation is advisable in many ways, it does not lend itself to the same practical use that is possible with a simpler descriptive name.

688. The equipment for survey work. — The most important part of the equipment for soil survey work is the field work. He should be a keen and careful observer, and he should have had broad training for his work. He should be acquainted with the technique of soil in the laboratory and in the field. He should be familiar with the chief physical and chemical processes and material involved in soil formation. He should have an understanding of those phases of geology known as physiography. On the agricultural side, he should be acquainted with plants and the methods of growing the more important crops. He should know tillage practices, and should be

¹ Hudlow, C. G., and Peck, J. W. The Practice of Micro-Soils. Illinois Agr. Exp. Sta., Bul. 225, p. 232. 1908.

able to distinguish between the properties of the soil that are native and permanent and those that may be induced by the method of handling. There is very little known, except of natural phenomena that will not be found useful to the field man in classifying soils, because he uses all sorts of subdivisions in making and checking his divisions in soils. In brief, he should have a good training in the fundamental science of geology, chemistry, and agriculture.

In the way of physical equipment the field man should have a good map of the region, so a scale of one inch to a mile or larger. The field work should be done as at least, perhaps a scale on the finished map, so this increases the degree of accuracy. The map should show the roads, streams, and towns of the region, and in addition the topography, location of houses, and other natural and cultural features which are useful in placing boundaries of soil. Where a satisfactory map is not available the field man must make such a map¹ during the progress of the soil survey. For this purpose a Cassini's plan table, a spirit alidade, and some method of measuring distances—preferably an odometer, such as is used for counting the revolutions of a heavy wheel—are necessary. Check-book drawing paper is generally used.

Where a suitable base map is already available, a set of pencils of different colors for representing each type of soil on the map as it is recognized is essential. A brown and bluish is the most useful of colors. For representing the soil a soil sugar is used (see Fig. 83). The remainder of a second one-half-inch round sugar attached to a half-inch pipe rod with a T-handle, making a total length

¹ *Instructions to Field Parties*. U. S. D. G., Dec. 6th, 1904.

of about thirty-eight inches. By the use of additional sections the length may be increased. The end of the auger may be modified by cutting off the screw and the cutting jaws, to better adapt it to the work in soil. Generally a bottle of anhydrous acid for detecting carbonates, and strips of sensitive litmus paper of red and blue for testing the soil acidity, are useful adjuncts to the equipment. In soil regions where important quantities of shells are met with, the field man should be supplied with a mechanical Winkler's bag and chemical equipment necessary for the detection and measurement of the important soil constituents.¹ A geologist's hammer for examining soil and rocks should be added, together with such other minor equipment as may increase the convenience and efficiency of the work.

A substantial field book should be provided, for notes on the character of soils, (54), nature of soil types and other observations and data, and for records of borings and samples. The notes should be carefully classified. Double bags of about one quart capacity should be used for collecting and shipping the samples to the laboratory for mechanical analysis. When the natural soil structure and

Fig. 82. Auger used in the examination of soils. (54), handle; (55), jaws; (56), cone with modified cutting edge.

¹ Deane, R. O. R., and Ryan, R. The Chemical Methods for the Determination of Soils in Soils. U. S. G. A. Bur. Soils, Bul. 10. 1906.

mineral condition of the sample are to be preserved, wide-mouth, wide-leg, metal or glass containers should be used. Aluminum cans are usually most suitable, as they are not corroded by the sample.

SOIL PROFILES IN THE FIELD.—The area for survey having been selected, the field party— which usually consists of one man, a dog and an assistant— proceeds to examine the soils of the district. Headquarters are temporarily established in a convenient village or nearby settlement, and excursions are made into the adjacent territory. The routes are laid out carefully and systematically with the purpose of examining the soils of the entire area. The party proceeds along the highway, with frequent stops and into excursions into the field, examining the soil to a depth of three or more feet with the auger. In forest regions the basis of the soil description is a section of well tilled top dump. In arid regions where shallow gravelly or stony soil is usually the basis of description, and occasionally such deeper excavations are made for studying the position of the water table. The soil is examined especially with reference to its texture, structure, color, drainage, content of organic matter, depth of different strata, and special chemical properties such as lime and alkali. The natural vegetation is observed, and note is taken of the type and growth of crops as well as the extent and species of forest here.

Diagrams and other observations are made from point to point as the appearance of the soil, the topography, the configuration of the country, and the character of the vegetation may suggest. The frequency and position of observations are determined entirely by the judgment of the field man. They may be made every few rods or at

much wider intervals. In getting acquainted with new types, most findings and detailed observations are necessary than after the soil properties have become familiar and can be more readily identified. Where the soil is highly variable, much more frequent observations are necessary than where it is more uniform. As the survey proceeds the field man progresses from point to point, along the highway and in the field, on foot or by motorcycle or even by more convenient, extending his observations about half the distance to the next highway in order that all the territory may be covered most conveniently. Usually the trip is arranged in a circuit. All areas of soil essentially alike in their properties and plant relations are recognized as of the same soil type, and their position on the map is represented by one of the colors. As the observations proceed, a change in the character of the soil may occur. Where this change because of such observations and experience as to cause differences in general relations and to be recognizable under the plan of classification outlined above, a new type is recognized. The boundary line between the two types must be carefully traced out by observation and by borings. As the work proceeds other types of soil may be recognized and the boundaries are determined and represented on the map, each type being indicated by a particular color or symbol. A large number of types of soil may be recognized in each area surveyed. The character and relationships of these must be studied carefully in order to decide how they may be grouped in series and higher units.

In practice it is usually better for the field party to first make general observations over the area, in order to recognize the main divisions of the soil that may later require subdivision into types. To this end, all available

facts, particularly concerning the geology of the region, should be furnished to the survey men before active field work is begun. It is easier and results in a greater degree of accuracy to first recognize the major divisions of an area of soil, and then work out the types that to be encountered from the very beginning entirely with these dominant subdivisions.

During the progress of the field observation the characteristics of each type of soil, its natural and cultivated plants should be studied, and the tillage properties of the soil noted. The farmer also may be interviewed concerning their soils, as to tillage properties, crop rotation, and response to methods of improvement. In short, all available data concerning the character of the soils of the region should be sought.

Records are made in the field notebook description of the average character of each type of soil. The characteristic of typical topography to be recorded and their location noted on the map. Preliminary samples may be taken and sent to the central laboratory for physical or chemical examination, to check the judgment of the field men.

22. Collection of soil samples.—Samples of soil for laboratory examination should be taken only after the field man is thoroughly familiar with each type of soil and can select a location that accurately represents the average material of the type. Attention should be given to the slope, drainage, cultural modifications, and natural treatment of the soil at that point. Therefore, in survey work samples are collected only in the better part of the season. One or more samples of each important type of soil are taken. The material, to the amount of a quart, is preserved in cloth bags. Usually each sample is divided into two parts, one representing

the soil and the other the subsoil. If there is a marked change in appearance or texture in the subsoil, other divisions of the sample may be made. Usually a composite of a number of borings over an area of several square rods, or even of several acres, may be necessary in order to secure an accurate sample and to obtain enough material. A composite of several representative borings made over a considerable area gives a more nearly accurate sample than is possible in a single boring. The possibility of local variations is very great, and their effect is reduced when composite sampling is done.

Each bag should bear a tag which is given a number and on which is placed the name of the type, the location of the sample in the section, and a brief description of the material. The same data are recorded in the field notebook, which is finally preserved as a part of the permanent office record of the survey. The description in the notebook may be simplified here (as is possible on the bag).

The location where each sample was taken should be accurately marked on the field map by a number corresponding to the number of the sample. Usually each sample is given a number, and the parts are indicated by a letter, proceeding from the surface downward. When the material is very wet and likely to become lumpy when dry, it may be dried in a thin layer before being finally bagged for shipping or preservation. Care should be bestowed on every part of the operation of collection, describing, numbering, bagging, tying, and shipping, in order to insure accuracy and permanency of the record.

The soil auger is generally used in taking the sample and in examining the soil section. The worm of the auger is forced into the soil until it is filled. It is then withdrawn and the soil is removed. The soil may be

collected on one or more layers of cobble, or it may be placed directly in the appropriate bags. The nose of the auger having been cleaned, it is inserted into the same hole and advanced until it is again full, when it is withdrawn and closed as before. This operation is repeated until the desired depth is reached. Where the soil is a very heavy clay, it may be advisable to only partially fill the nose with soil. Where the soil is very dry and yulcrum to a hard, it may dig off the nose, in which case water may be added to make it adhere. The upper part of the hole should be cleaned, and it may be slightly enlarged so as to prevent contamination with the material from the lower part of the section. Where there are rocks at the surface, this should be removed previous to beginning the collection of the sample.

In very heavy soil the auger is not suited to taking a sample, either for examination or for sowing. In such soil a shovel may be used, or the sample may be taken in a hand or some other sort by means of a probe or hammer.

The face of the section should be removed to a depth of several inches, in order to eliminate crusts or any laminated material which may not be typical of the soil section. Usually a difference in color and physical properties of the soil indicates a modification of the typical material.

66. The accuracy and detail of the soil survey. The accuracy and detail of the soil survey depend on many things. Assuming an adequate preparation on the part of the field man, there are limitations to accuracy imposed by the tools by which the map is made and the nature of the soil. The smaller the scale of the map used in the field, the less the detail that may be represented. The measurement scale employed is one inch to a mile. Some

states on a large scale, and in reconnaissance surveys a smaller scale is used. While a large scale increases the detail that may be represented, it also multiplies the difficulties of making an accurate classification because it increases the number of properties to be observed.

The nature and occurrence of soils in the field involves more variations than can be shown on the map. The boundaries of soil types grade into one another, and it may not be possible to make the division into several soils. Sometimes even a wider range occurs. The accuracy with which the boundary may be determined and drawn depends very much on the way in which the two adjacent soils have been found. If they are very different, the boundary may be very distinct. Some types of soil are characterized by local variation in position or from point to point, which on a too small a scale is to be interpreted as a type. Variations may be induced in a type due to differences in topography, drainage, or cultivation. Where the properties do not hang about an important change in the way relations of the soil, they may be ignored. Differences due to utilization are generally disregarded. The soil survey is made to cover a period of years, and only permanent differences should be considered.

Variations in the soil must be considered in relation to the scale of the map. On a scale of one inch to a mile the minimum area that can be shown is about ten acres. Occasionally, where the difference in type constitutes a striking contrast, the small area may be somewhat overestimated in size. An area of wood soil having high value for the production of truck crops might be such an exception.

630. The soil survey report.—The soil survey report consists of two parts, the printed report and the map showing the distribution of the soil types. The printed report accompanying the soil map should be a brief but comprehensive summary of the observations of the field party in the areas surveyed. It should cover in general information: (1) location and boundaries of the area; (2) general physical features; (3) climate; (4) agricultural history and development; (5) description of the soils; (6) suggestions for improvement in the management of the soil that may have been determined by the survey.

The description should point out the salient topographic forms, the range in elevation, the nature and development of the drainage, the transportation facilities, and the distribution of population and of farm areas. The discussion of climate should note the monthly mean temperatures and amount of precipitation; the character of the extreme ranges in place, the direction of prevailing winds; and the occurrence of any special features, such as seriously frosts, gales and hail and windstorms, and the nature of local variations in climate that may be due to the proximity of bodies of water or topographic features. The agricultural history should note the source and character of the agricultural population, the chief products and any changes that have occurred in their production, and the present status of the area.

The description of the soils should be in two parts. First, the grouping of the types into series and larger divisions, with the pedologic and topographic relations of these groups and a brief statement of the characteristic properties of each group. Any important characteristics that are common to two or more types or series, such

6 as a deficiency in lemons, limes, or cherries, should be pointed out. Similarly, a detailed description of each type following a uniform outline of properties, including color, texture, depth, structural predominate, and mineralogical and chemical features. Following this, attention should be drawn to the location and extent of the type in the area, and to its mode of origin, drainage conditions, and economic relations, including the crop rotation and extent of development.

In making suggestions for the treatment of the soil a clear distinction should be drawn between methods of soil management and improvement, and questions of farm organization and management. The data collected by the soil survey man will usually tend him to confirm his suggestions to the former group.

221. The soil map (Fig. 86). - The soil map is designed primarily to show the geographic position and extent of each type of soil. Therefore an accurate base map, showing important natural and cultural features as noted above, is essential. The color of the map must be adapted to the amount of detail to be shown. The measurement scale in use in the United States is one inch to a mile. In reconnaissance surveys a scale of one inch to six miles is usually employed. The map is printed in colors or in symbols representing the different types of soil. Symbols may be added to the color to indicate further variation, such as the presence of stony clays, obstruction of ledge rock, or a source condition. On the right-hand border of the map a legend to the colors or symbols is given, and they may be arranged in accordance with the scheme of classifying the soils to show their relationship. On the left-hand border, the character of the profile of each type of soil is indicated by a series of legends.



No. 14.—Part of the Madison County, N. T., and map showing the topographic and the relative of the various and given to one another.

68. **The extent of soil surveys in the United States.**—The detailed survey and mapping of soils by the Bureau of Soils of the United States Department of Agriculture, according to the system outlined above, has been in progress since 1906. On January 1, 1916, about 250,000 square miles had been covered by detailed surveys and 550,000 square miles had been covered by reconnaissance surveys. In addition, several miscellaneous groups have been made in various provinces such as Porto Rico, Panama, Philippine Islands, and Alaska. The total number of soil types and series recognized is approximately 2,000 and 600, respectively.

69. **Surveys by state institutions.**—Several states are engaged in soil survey work, either independently or in cooperation with the United States Bureau of Soils. The states that have undertaken this work independently have carried it out in the same general manner as in the Federal surveys. Some of the states that are working independently have confined their investigations to more extensive surveys on a large scale. Tennessee has published a general report, with a map, on the soil areas of the state, with special reference to their geological relations. *Arizant* is also taken of the history, chemical composition, and other properties. Iowa, Missouri, and Illinois and Ohio have published similar general reports showing soil areas based chiefly on color, texture, humidity, and base content have also published detailed reports on particular areas. In their work the principles of classification laid down above have been followed in a general way, but with suggestions on certain selected properties.

¹ Galloway, C. M., and Shaw, T. D. *Humus-mannan Soil Survey of Ohio*. U. S. Bur. Soils, Publ. 79, p. 301. 1915.

Illinois has given special prominence to color, and, in addition to the general description of the soil types, includes data derived from chemical analyses to show the mineral plant-food in the surface layers. The Indiana and Missouri surveys have combined a purely geological scheme of classification on the basis of origin, with certain properties of practical importance, such as texture, color, and content of humus, but without observing a systematic order. The New Jersey survey includes rather full data on the chemical composition of the soil types, in addition to the usual discussion of their properties and relationships.

63. *Surveys in other countries.*—Several countries have undertaken some type of soil or agrogeological surveys. These surveys, which have been undertaken in Germany, France, Italy, Russia, Great Britain, and Japan, have aimed at a broad practical classification of soils based on their agricultural values and climate properties. Several thousand square miles have been covered by the surveys in each of these countries. Colored charts are published to accompany the descriptive reports. In these surveys the classification is largely genetic, in connection with a consideration of the more evident physical and chemical properties, which are recognized and grouped in the field in much the same manner as in the American surveys. The details, of course, are considerably different in the reports of the different countries. In Germany the maps are geological-agronomic in character; that is, prominence is given to both the geological and the crop relations of the soils. Their physical and chemical properties are printed out and are used in the classification. Similar methods are followed in France and Japan.

In England the uses of soil are determined, first, by means of their texture; secondly, by means of their col-

best of farmers and their cartographers, with stable soils and drainage are inevitably, and chiefly, by means of the geological knowledge and study of crops. Fully complete, exhaustive and detailed studies of representative samples of the important types are needed, and the solution of the soils to crops and their position is discussed at some length. The grouping of the types into soils, groups, provinces, and the like, is put as distinct as the farmer's research. Thus the fundamental importance of the deeper factors in classification are recognized in terms of the discussion of the relation of population and transportation to the properties and agricultural uses of the soil, in which the controlling influence of these considerations cannot be denied.

But there of the soil survey. — The soil survey is useful in many ways, but it is not a final investigation. It is to be regarded rather as a means of determining the nature of the soil and related conditions in the field. These may throw light on many facts, position and kind to their importance. More frequently the soil survey points to lines of further investigation that should be carried out.

The second fact of survey may be immediately divided into two groups — the first in the soil itself, and the second in the study. For the first, the soil survey (1) points out the character and location of the soil types of soil or the farm which may be compared with particular crops and their position; (2) shows the relationship of soils and crops, which may have a basis for the selection of new crops or new methods of soil management; (3) provides a reliable method of information concerning soil conditions; (4) establishes methods of description and representation of soils; (5) reveals in

many cases important problems of soil improvement that need attention; (3) affords a guide in the selection of soil estate and in the selection of land for particular purposes. For the state soil survey: (1) shows the soil resources; (2) by the selection of the state of a central point, affords the basis for the selection of all other types of information, the character of which is affected by the soil relations; (3) shows in many cases the occurrence and importance of large quantities of soil improvement, and may point out the need for further investigations; (4) gives a basis on which much of the results of experiments, investigations, and observations on soil improvement, crop growth, and in many cases farm management, should be reported; (5) is a means of communication and mutual understanding between the state institutions concerned with agricultural information and the individual farmer; (6) by affording a basis of facts, practices must commercial, social, and governmental development.

The soil survey is essentially an inventory of the resources in land and closely related interests. It helps the farmer to understand the situation of his farm and its relations to other farms. It helps the state to get acquainted with its domain, and promotes a better sense of mutual understanding and helpfulness. The soil survey in some form is an essential step in sound economic breeding, for the success of most interests—commercial, social, and institutional—rests ultimately, to a large extent, on the character and value of the soil.

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